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Skywatchers of Ancient Mexico



Skywatchers of Ancient Mexico

by Anthony F. Aveni

FOREWORD BY OWEN GINGERICH

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Foreword

MANY YEARS AGO the editors of *Scientific American* told me that there were two magically appealing subjects at least one of which they invariably tried to include in every issue: archaeology and astronomy. The romance of space and the mystery of the past!

But to combine astronomy and prehistory does not necessarily augur success. I am reminded of the would-be-best-seller-writer who combined the three statistically most popular title words into *Lincoln's Doctor's Dog*, only to produce a miserable flop. What is needed is interdisciplinary professional competence and imaginative insights combined with a well-grounded skepticism.

These qualities accompany Professor Aveni in his examination of Middle American astronomy. Not a text in archaeoastronomy as such, it is nevertheless the first full-length book coupling basic astronomy with archaeological and ethnological details. Aveni skillfully brings the tool kit of the emerging discipline of archaeoastronomy to bear on the pre-Columbian skywatchers of the New World. Those of us working primarily on the history of Old World science can only hope that the insights achieved in the Western Hemisphere studies will illuminate the history of astronomy in the more traditional civilizations. For example, it has apparently escaped notice that the cyclical Venus tables of the Maya bear a strikingly close resemblance to the Babylonian goal-year texts and to medieval tables, such as those eventually published in Spain by Zacuto around 1500. Similarly, the Maya concept of eclipse "danger periods" has a notable parallel in the ancient Chinese approach to this topic. In contrast, the astronomy of the Egyptians and of the Stonehengers seems horizon based, whereas in the tropics the vertical phenomena of overhead passages appear to take precedence. How these strands are linked or diversified across ocean barriers remains one of the enigmas not yet approached by these studies. When or whether the veil of obscurity will be lifted only the future can reveal. In the meantime, we must applaud these efforts to clarify, to make more accessible, and to extend the knowledge of ancient astronomy in the New World.

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Anthony F. Aveni

Skywatchers of Ancient Mexico

I. Introduction: Archaeoastronomy and Its Components

"... Maya astronomy is too important to be left to the astronomers."

—Sir Eric Thompson (1974, p. 97)

ALL DEVELOPING CIVILIZATIONS exhibit a reverence for the sky and its contents. The cyclic movement of the sun, moon, planets, and stars represents a kind of perfection unattainable by mortals. The regular occurrence of sunrise and moonset provided the ancients with something dependable and orderly, a stable pillar to which their minds could be anchored.

Today we no longer have need of practical astronomy in our daily lives. Unlike our ancestors, we spend most of our time in a regulated climate with controlled lighting; we are detached almost totally from the natural environment. Technology has created an artificial backdrop against which we play out our lives. Any need we once had to watch carefully for celestial events has become lost. Who knows the time the sun rose today or the current phase of the moon? The clocks by which we pace our daily activities give us a distorted view of the dependence of real time periods upon circumstances transpiring in the heavens.

Though we may try, we cannot really appreciate the degree to which the minds of the ancients were preoccupied with astronomical pursuits. Modern science and technology have flavored our way of thought so as to rob us of any real sensitivity to the nature of the ancients' relation to the cosmos. The heavens touched nearly every aspect of their culture; consequently, we find ancient astronomy woven into myth, religion, and astrology. So great was the reliance of the ancients upon the sun and moon that they deified them. Representations of these luminaries adorned their temples as objects of worship and they were symbolized in sculpture and other works of art. The ancients followed the sun god wherever he went, marking his appearance and disappearance with great care. His return to a certain place on the horizon told them when to plant the crops, when the river would overflow its banks, or when the monsoon season would arrive. The planning and harvesting of crops could be regulated by celestial events. The important days of celebration and festivity could be marked effectively using the celestial calendar. Equipped with a knowledge of mathematics and a method of keeping records, the ancients could refine and expand their knowledge of positional astronomy. After several generations, with the

advantage of a "written" record, they could learn to predict such celestial phenomena as eclipses well in advance. What a powerful advantage the priest-ruler would have over his followers with this bit of trickery in his repertoire.

We are continually amazed at the seemingly impossible accomplishments of our ancient ancestors. How did they erect the great pyramids, the statues on Easter Island, or the huge Olmec heads? In disbelief, some of us turn to extraterrestrial zoo keepers for the source of ancient wisdom and ability. According to one popular account, "the past teemed with unknown gods who visited the primeval earth in manned spaceships. Incredible technical achievements existed in the past. There is a mass of know-how which we have only partially rediscovered today" (Daniken, 1971, p. vii).

Though the last part is substantially true, such a statement is uttered in total ignorance of the ways of ancient people. One of the goals of this text will be to show that the sophisticated astronomical and mathematical achievements of the people of ancient Mesoamerica followed logically in the evolutionary development of a civilization which intensely worshipped the heavens and steadfastly associated the phenomena they witnessed in the celestial environment with the course of human affairs.



Since the ancients expended considerable effort paying tribute to their celestial deities, we should not be surprised to find that, in many instances, astronomical principles played a role in the design of the ceremonial centers where they worshipped their gods. Stonehenge is perhaps the most famous example of an ancient structure believed to have served an astronomical function. In 1964, astronomer Gerald Hawkins wrote *Stonehenge Decoded*, thus rekindling an idea made popular at the end of the nineteenth century by Sir Norman Lockyer. Hawkins hypothesized that the megaliths standing for five thousand years on the plain of southern Great Britain constituted a calendar in stone, each component situated deliberately and precisely to align with astronomical events taking place along the local horizon. Detailed works by Alexander Thom (1967, 1971) and a cultural synthesis by Euan MacKie (1977) have since solidified the basis of our understanding of ancient megalithic astronomy and have elevated it to a level of scholarly respectability.

The Stonehenge controversy has been responsible for the resurgence of interest in the interdisciplinary field of astroarchaeology, a term first coined by Hawkins (1966) to encompass the study of the astronomical principles employed in ancient works of architecture and the elaboration of a methodology for the retrieval and quantitative analysis of astronomical alignment data. An alternate term, "archaeoastronomy," embodies the study of the extent and practice of astronomy among ancient civilizations. Such a definition fits the discipline which classicists call the "history of astronomy," except that the latter has dealt traditionally with the literate Western society and focuses largely on analyses of notational schemes in the Western style (i.e., ancient scriptures, Egyptian hieroglyphs, cuneiform tablets). Being somewhat less confined by tradition and often handicapped by the sparsity of a written record, archaeoastronomy has developed into a broader in-

terdiscipline drawing upon the written as much as the archaeological and iconographic record. Consequently, discussions of astronomical symbolism and astronomical precision are often intermixed.

Though much emphasis has been placed on the megalithic sites in Europe, an increased interest has recently arisen in the study of astronomical building orientations in other parts of the world, particularly the Americas. Aerial photography has revealed that the remarkably straight lines etched across the Peruvian desert at Nazca continue up and down the steep sides of mountains for distances of several miles. Many of these lines are oriented to the rising positions of the sun at the solstices. Large figures at their intersection may have symbolized the constellations. In Central Mexico, the plan of the great ceremonial center of Teotihuacán seems to have been organized to harmonize with the positions of the sun and certain fundamental stars. Astronomical orientations have also been discovered in the Maya area of the peninsula of Yucatán. The so-called Group E structures at Uaxactún, Guatemala, represent the prototype of a series of sun watcher's stations found in that region. The Caracol at Chichén Itzá in Yucatán, an observatory in the shape of a round tower, contains horizontal sight tubes directed to positions of astronomical significance.

Anthropologists have become interested in studying relationships between the astronomical knowledge of civilizations of Mesoamerica and that of the native tribes of North America. Did cosmological ideas diffuse among the cultures and which concepts developed independently? Ceremonial mounds near St. Louis, Missouri, and in central Kansas probably functioned as solstice registers to mark the extreme positions of the rising sun. The Big Horn Medicine Wheel, a spoked wheel formed out of boulders in the mountains of Wyoming, also appears to have functioned as an astronomical observatory. Far to the south, the interconnected lines of the *ceque* system surrounding the ancient city of Cuzco in Peru may represent a calendar on the landscape which has astronomical, religious, and even political attributes.

In the Americas, a number of investigators from widely divergent fields have turned their attention to archaeoastronomical pursuits. As a result of the unique cooperation among them, there has been added to the literature an increasing body of evidence relating to the role of astronomy in the lives of the ancient people of this hemisphere. After a decade of progress on several fronts, it is time to begin the slow process of synthesis of the new material into the mainstream of human intellectual history.

This book is about the people of ancient Mexico and Central America and what we know of their system of astronomy. In studying them we have an enormous advantage over Thom, Hawkins, and their predecessors, for we know from the written record, the art, and the sculpture that the civilizations which developed in the New World before the arrival of Columbus were already highly advanced by the time of his arrival. Only within the last half-century have we begun to gain a full appreciation of the magnitude and sophistication of ancient New World civilizations. The ancient American calendric documents reveal that mathematics and astronomy were among their intellectual hallmarks; in fact, they were fanatically devoted to these disciplines. For

them, time was an intricate natural system, each day being ticked off in a complex maze of endless cycles. But quite unlike our modern astronomy, the *raison d'être* of Mesoamerican, particularly Maya, astronomy was ritualistic and divinatory in nature.

To have accomplished as much as they did, the ancient Americans must have been keen observers of the heavens. Were they also brilliant theoreticians? To answer such a question we must assemble, all in one place, the material which is relevant to an objective assessment of the depth and extent of their astronomical knowledge. I have set such a goal in the production of this volume. In attempting to achieve it, I have necessarily ventured a few steps out of my own field in different directions in order to form canals between pools of material in disciplines usually regarded as unrelated. Any true interdisciplinary synthesis requires that such steps be taken. In cutting the path, I have made a special effort to tread softly, accepting the generous guidance of interested colleagues in allied fields.

Because an interdisciplinary approach to archaeoastronomy has developed, the serious scholar must become acquainted with certain segments of established fields which border upon it. What are these segments of knowledge? It seems clear that an understanding of basic positional astronomy is indispensable if one wishes to master the complexities of ancient astronomy. Maya archaeologist Sir Eric Thompson once suggested that one could understand Maya astronomy only by getting into the skin of the Maya priest-astronomer. In other words, a knowledge of the history and culture of the Native American people is vital to an understanding of their astronomical systems. Input from the archaeological discipline is important since it represents a large part of the record which survives. Pre-Columbian astronomy was strongly wedded to astrology and religion. Those of us trained in the modern sciences must be careful not to slant our view too much toward the present. We cannot assume that the Maya were always looking for the same celestial events which matter to us. Some astronomers, with a poor grasp of pre-Columbian thought, have made assertions about the Maya calendar which are strongly at odds with the facts gleaned from the anthropologists' studies.

Too often discussions of ancient astronomical systems have been couched in one-sided dialogue. The twentieth-century Western scientists are accused of fashioning their ancestors after their own image; they frame their arguments in the scientific jargon of their profession. As a result, the anthropologists either blindly accept their propositions out of awe and reverence for the complexity of their language and scientific method or refuse to consider the argument because they cannot comprehend the intricacies of positional astronomy delineated in tracts that were never intended for the nonscientific audience. Conversely, many outrageous astronomical statements have been uttered by untrained anthropologists, who, with a little understanding of elementary astronomy, could have carried their theories a long way.

Goal This volume, it is hoped, will introduce all readers to the basic components of the interdisciplinary field of archaeoastronomy. It is offered as a bridge connecting the established disciplines of astronomy, archaeology, culture history, and the history of astronomy and is in-

tended to serve as a platform for the exchange of ideas among students of these seemingly disparate fields. Since the synthesis is presented at an elementary level, the text should benefit the interested lay person as well as the informed visitor to the ruins.

We begin by staging a background for our studies with a brief chapter on the ethnological basis for ancient American astronomy. This chapter serves to give the reader a general orientation for how ancient New World people viewed the heavens around them. Because of the wanton destruction of pre-Columbian sacred documents by the Spanish invaders, we have relatively little to work with in this area: portions of four original Maya manuscripts and a handful of others from Central Mexico; statements (some more reliable than others) in the brief histories of the native people written by Spanish missionaries who traveled to the Americas shortly after the conquest; and bits of data gathered by ethnographers traveling among the survivors and progenitors of the conquered people, some of whom still practice ancient rituals.

William Bell Dinsmoor, the Columbia University archaeologist, stated that if one were to seek an explanation for the disrepute into which the study of building orientation had fallen by the 1930's it might be attributed to the "niceties of modern astronomical calculation. What would have been a simple process in antiquity, the mere observation of the point of rising or setting of the sun, or as some think, of a certain star, on a selected day in the then current year, must now be laboriously reconstructed" (1939, p. 102).

This problem might have been remedied if the astronomical community had provided anthropologists with a discussion of that portion of their discipline that was relevant to the orientation question. Chapter III, on positional astronomy, is intended to serve as a user's guide to the celestial sphere and its contents. Different from the treatment found in standard astronomy texts, this chapter is especially slanted toward naked-eye astronomy, particularly as it applies in the tropical latitudes where Native American civilization developed. The nonessentials found in most standard astronomy texts have been removed. Basically, the investigator wants to know: What are the significant astronomical events which might have been watched by the ancients? Given no technological aids, what are the possible procedures for determining the time and place of occurrence of such events, and with what accuracy can they be observed? How has the appearance of certain astronomical phenomena changed since the time ancient culture developed? How can we retrieve astronomical information from quantitative measurements obtained at the archaeological ruins? Questions of this nature are addressed in some detail, with an emphasis on cyclic phenomena, an aspect of the heavens which is most easily observed by naked-eye astronomers. A background in elementary geometry is assumed. For those already possessing a knowledge of practical astronomy, this chapter may be only briefly reviewed or, perhaps, considered as a reference appendix.

Chapter IV is devoted to a discussion of the most well treated, yet thoroughly isolated, subtopic in Native American astronomy—the Mesoamerican calendar, one of the most sophisticated timekeeping

systems ever conceived by ancient people. Though many scholars who have written about it have focused their attention on the decipherment of the hieroglyphs and the question of how to correlate Old and New World chronologies, the treatment accorded the calendar here will be weighted heavily toward practical astronomy. Serious readers will become familiar with the fundamental operation of the calendar, the decipherment of dates, and the elusive problem of the correlation of the Maya and Christian calendars. They will also be asked to reflect upon how the elements of the calendar relate to the naked-eye astronomy to which they have already been exposed and from which the calendar derived. How, as the inscriptions suggest, did the Maya predict eclipses and how did they determine the length of the Venus year and the lunar month to accuracies of less than a day in several centuries? What sort of observations were required and what was the *modus operandi*? When did the astronomy become "scientific"? Such questions apply to the astronomy of any ancient culture.

Chapter V, on astroarchaeology, discusses the role of astronomy in the design and arrangement of ceremonial centers. A survey of field studies on the arrangement of Mesoamerican cities and ceremonial centers will be presented. Beginning with a discussion of the curious systematic orientation of the principal axes of many ceremonial centers, the chapter continues with an analysis of certain specialized buildings possessing peculiar shapes and orientations. Other case studies of astronomical alignments in ancient New World architecture outside Mesoamerica will be surveyed for comparison.

The reader of this text ought to be able to draw definite conclusions about the mental accomplishments of our predecessors on this continent. This book is both a synthesis and a personal view, operating with no predisposition toward proving theories for which no evidence exists. Rather, it is intended to serve as a marketplace where the ideas and evidence on issues demanding increasing attention in the field of prescientific astronomy can be assembled. Out of such an assemblage, I hope, will come the gradual synthesis of our renewed understanding of the cosmic mental system with other elements of Mesoamerican culture. Only then can a meaningful comparison of Old and New World systems of thought be initiated.

II. The Historical and Ethnographic Background for Native American Astronomy

"Who were the builders of these American cities? They are not the works of people who have passed away and whose history is lost but of the same races who inhabited the country at the time of the Spanish conquest . . ."

—John Lloyd Stephens (1843, 2:307)

THE CIVILIZATIONS OF ANCIENT MESOAMERICA

The Western world did not become aware of the existence of an advanced civilization in the Americas until John Lloyd Stephens and Frederick Catherwood toured Central America in 1839–1840. Together, author and artist produced two sets of volumes, *Incidents of Travel* (Stephens, 1841, 1843), which became instant revelations for both layman and scholar. In words and pictures Stephens demonstrated that the achievements of the ancient Maya in the fields of art, sculpture, architecture, and writing were on a par with the Classical civilizations of the Western world. As the quotation heading this chapter suggests, Stephens correctly attributed all these accomplishments to an indigenous race of American people.

The historical and archaeological record tells us that Mesoamerica, the region bounded on the north by the Tropic of Cancer and stretching as far south as the northern border of Honduras, was originally populated by nomadic peoples from Central Asia who crossed the land bridge into Alaska late in the Pleistocene epoch, 30,000–50,000 years ago. These early people wandered with the seasons, hunting and gathering their food supply as they went, but by 2500–2000 B.C., which anthropologists call the Early Formative period, isolated pockets of sedentary civilization developed and an agricultural system based principally upon maize took hold. This period also saw the beginning of pottery making and the expansion of an organized pattern of village trading. The extent of the Mesoamerican world in space and time is illustrated in the map and Table 1.

It is impossible to state when the people of Mesoamerica attained that sophisticated condition of human society termed "civilization." So many factors are involved in the definition of that term, and the material evidence is very scant. What Mesoamerican archaeologists call the Pre-Formative period began about 2500 B.C. with the appearance of pottery. A settled village life developed in the "Olmec Heartland" with

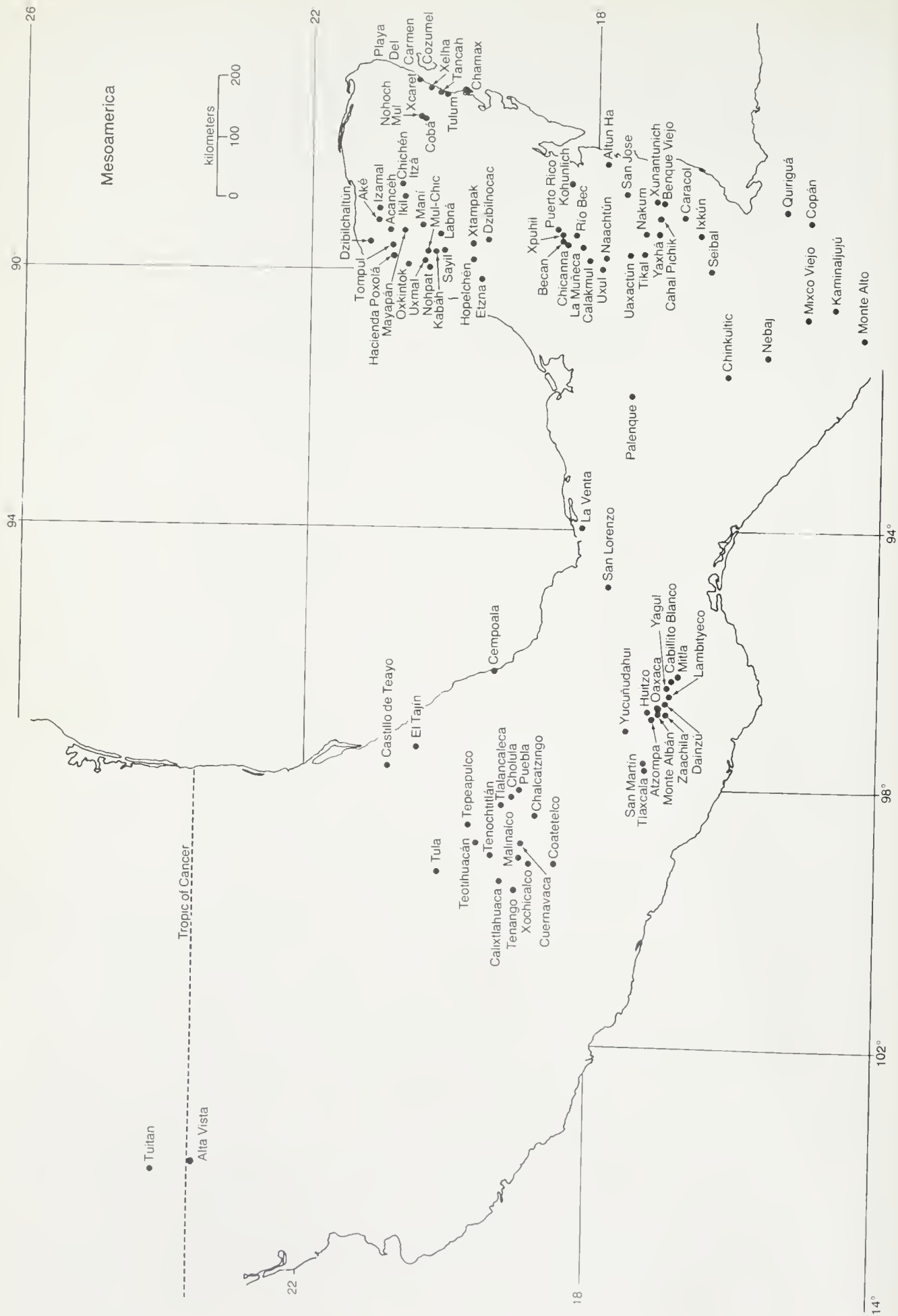


Table 1. *Old and New World Chronologies*

New World		Old World
Farming and the cultivation of corn	5000	
Settlements	3500	Sumerian civilization
Pottery	3000	First Egyptian pyramids
	2500	
	2000	Stonehenge
	1500	
	1200	Trojan War
	1100	
	1000	
	900	
	800	Homer
	700	
	600	Golden Age of Greece
	500	Etruscans in Rome
	500	Socrates
	400	Empire of Alexander the Great
	300	
	200	
	100	Carthage falls to Rome
	B.C.	Julius Caesar
	A.D.	
	100	
	200	
	300	Roman Empire
	400	
	500	
	600	Anglo-Saxon control of England
	700	
	800	Charlemagne
	900	
	1000	Vikings in North America
		William the Conqueror invades England
	1100	Crusades begin
	1200	
	1300	Magna Carta
	1400	Renaissance in Europe
	1400	Crusades end
		Fall of Constantinople
	1500	Spanish exploration of the Americas

farming based on corn, beans, and squash. By the Formative period (ca. 1500 B.C.), the great Olmec ceremonial centers of Tres Zapotes, La Venta, and San Lorenzo flourished.

In the Middle Formative period (1000–300 B.C.) settlements sprang up in the Valley of Mexico and Oaxaca. It is from about this time that the first concrete astronomical achievements can be documented. The end of this period saw the beginnings of hieroglyphic writing, a 365-day year, and the mysterious 260-day cycle on the first carved stelae (upright stone slabs). This period was characterized by rapid advances in the arts and sciences as well as great architecture and sculpture accompanied by increasingly complex political and social systems. The highly stylized Olmec art of the Gulf coast strongly influenced the nascent Maya civilization which was soon to grow up to the east in the Yucatán peninsula. Massive pyramids, like the one at La Venta (20,000 square meters at the base), began to serve as the focal points of sacred ceremonial complexes. Temples and pyramids emerged in greater numbers from the jungle as the people strove to get closer to their celestial gods.

The period of greatest sophistication in the civilizations of Mesoamerica occurred during A.D. 300–900, a time when Europe slept in intellectual darkness. Called the Classic, or Florescent, period, this era was characterized principally by the appearance of highly organized settlements, an advanced calendar, a complex religious pantheon, and the rise of a social elite class.

Nowhere were the qualities of advanced civilization and intellectual achievement more outstanding than in the land of the Maya. Tikal's incredible architecture, the delicate sculpture of Copán, and the exquisite stucco work of Palenque seem unsurpassed in the New World and rival the Old.

A combination of circumstances, among them mismanagement, a popular revolution, and possibly a change of climate, led to the precipitous decline of this culture by the tenth century A.D. Why the fall was so widespread and complete remains a mystery. The Maya gave up their obsession for carving calendar dates on stelae, entombing their dead kings, and continually refurbishing their massive architectural works. They fell back to a simpler existence. By the time the Spanish invaders arrived early in the sixteenth century, the native villages were generally decadent and in great disunity, a factor which complicated and prolonged the conquest. Twenty years earlier it was a simpler matter for Cortez, already hailed as the returning god Quetzalcóatl by prophecy, to break the bond of the ruling Aztec hierarchy and gain the day's advantage in short order. What little remained of one of the great civilizations of the world was thus almost totally muted in less than a single generation.

Excellent brief histories of the civilizations of the Americas are cited at the end of this chapter. The readers who avail themselves of the general historical background contained therein should better understand how the astronomical accomplishments of these ancient people fit into their total culture.

Diego de Landa, first archbishop of Yucatán, writing shortly after the Spanish conquest, proudly tells the sad tale of the fate of the written legacy of the ancient Maya. He refers to a great book burning which took place at the Yucatecan city of Maní: "We found a large number of books in these characters [hieroglyphs] and, as they contained nothing in which there were not to be seen superstition and lies of the devil, we burned them all, which they regretted to an amazing degree, and which caused them much affliction" (1941, p. 169).

The chronicler Juan de Acosta also refers to Maya books and what happened to them: "... there used to exist some books of leaves, bound or folded after a fashion, in which the learned Indians kept the distribution of their times and the knowledge of plants, animals, and other things of nature and the ancient customs, in a way of great neatness and carefulness. It appeared to a teacher of doctrine that all this must be to make witchcraft and magic art; he contended that they should be burned and those books were burned and afterwards not only the Indians but many eager-minded Spaniards who desired to know the secrets of that land felt badly" (1590, bk. VI, p. 6).

Fragments of only four original Maya manuscripts, or "codices," (the Dresden, Paris [Peresianus], Madrid [Tro-Cortesianus], and Grolier) survive today. All carefully painted on bark paper fashioned into a folded-screen document, the writing and pictures contain a wealth of information pertaining to the heavens: lunar and solar almanacs, even a Venus ephemeris usable for one hundred years. Though a few more codices survive from Central Mexico, the bulk of Mesoamerican written documents have been lost or destroyed. In many cases, we must rely on statements of the historians of the postconquest period, many of whom we wish had recorded their observations more carefully. (See Chapter IV for a full discussion of the codices.)

Fig. 1, taken from the Madrid Codex (1967), a Maya document written shortly before the conquest, reflects the central role of astronomy among the civilizations of Mesoamerica. An astronomer is observing the stars. Seated at his station, he seems to be plucking them out of the sky with his extended eyes. The skywatcher is surrounded by hieroglyphs and Maya numbers which presumably relate to his astronomical secrets.

Stargazing seems to have been a common occupation among the nobility. The Spanish historian Torquemada, writing a century after the conquest, tells of the astronomical pursuits of Netzahualpilli, the king of Texcoco: "They say he was a great astrologer and prided himself much on his knowledge of the motions of the celestial bodies; and being attached to this study, that he caused inquiries to be made throughout the entire extent of his dominions, for all such persons as were at all conversant with it, whom he brought to his court, and imparted to them whatever he knew, and ascending by night on the terraced roof of his palace, he thence considered the stars, and disputed with them on all different questions connected with them" (1969, vol. 1, bk. 2, chap. 44, p. 188).



FIG. 1. An astronomer in the Madrid Codex. (Courtesy of Akad, Druck-u. Verlag, Graz)

Torquemada goes on to tantalize us with a poorly worded statement about the astronomer's methods of observation (which he evidently did not understand): "I have seen a place on the outside of the roof of the palace, enclosed within four walls only a yard in height, and just of sufficient breadth for a man to lie down in; in each angle of which was a hole or perforation, in which was placed a lance, upon which was hung a sphere; and on my inquiring the use of this square space, a grandson of his, who was showing me the palace, replied that it was for King Netzahualpilli, when he went by night attended by his astrologers to contemplate the heavens and the stars; whence I inferred that what is recorded of him is true; and I think that the reason of the walls being elevated one yard above the terrace, and a sphere of cotton or silk being hung from the poles, was for the sake of measuring more exactly the celestial motions."

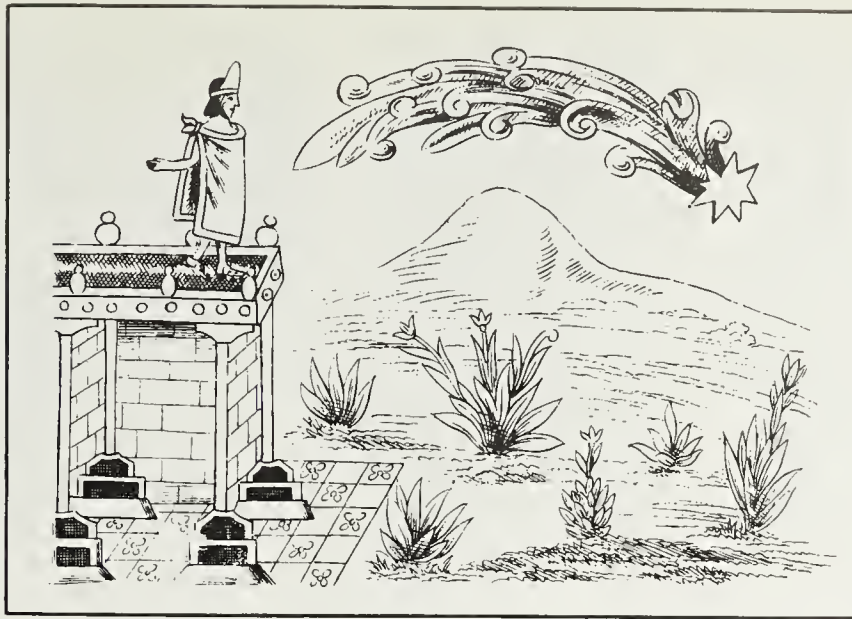


FIG. 2. A great comet was said to predict the fall of Moctezuma's empire. (Durán, 1951, fig. 24, courtesy of Editora Nacional, S.A.)

Further evidence of Netzahualpilli's careful attention to the heavens is exemplified in the episode of the great comet which was said to have presaged the fall of the Aztecs (Fig. 2). The chronicler Father Diego Durán tells us that Moctezuma, having observed the comet since midnight, went the next day to Netzahualpilli to seek its meaning. Replied the king of Texcoco, "Your vassals, the astrologers, soothsayers and diviners have been careless! That sign in the heavens has been there for some time and yet you describe it to me now as if it were a new thing. I thought you had already discovered it and that your astrologers had explained it to you. Since you now tell me you have seen it I will answer you that that brilliant star appeared in the heavens many days ago" (Durán, 1964, pp. 247–248). He goes on to give details of the frightful omens that soon after befall the unfortunate monarch.

From such statements about their astronomers it is difficult to grasp the cosmological viewpoint espoused by these ancient sky-watchers. We know, from reading other authors that the Mesoamerican priests conceived of a layered universe, each stratum containing one category of celestial body (Fig. 3). Above the layer of the earth, the moon traveled its heavenly course. Above this moved the clouds, the stars, the sun, Venus, comets, and so on, with the male-female creator god occupying the thirteenth and uppermost layer. The underworld consisted of nine divisions, if we count the earth as the first, stacked in an orderly fashion below earth. This view is quite in contrast with both the geocentric (earth-centered) and heliocentric (sun-centered) views of the universe which evolved in the classical Western world.

While the place of humans in the layered cosmology seems to be given some added importance over the rest of the system (the earth is counted twice), nevertheless, the concept of the earth as the center of the universe is not even suggested. The orbital theme which dominates

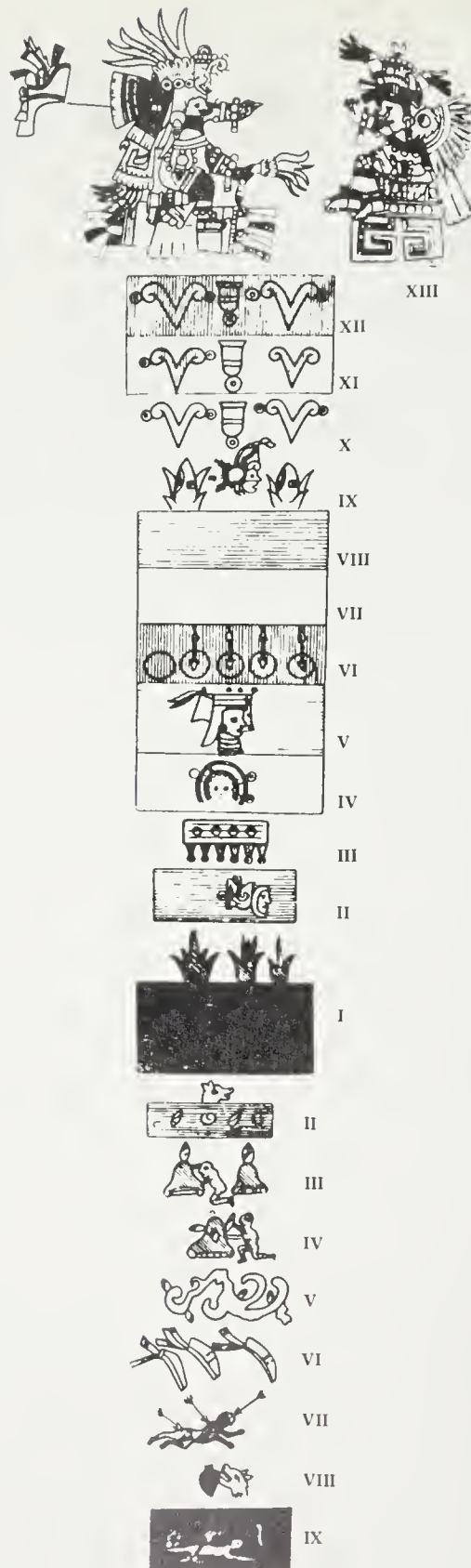


FIG. 3. All of space is layered, with nine layers of underworld and thirteen of heaven, the earth (I) being counted in each. The sun (IV), moon (II), Venus (V), and the constellation of the Fire Sticks (VI) are important enough to occupy levels of their own. From the Codex Vaticanus. (Courtesy of Akad. Druck-u. Verlag, Graz)



FIG. 4 Chronology represented one of the earliest demands made upon New World astronomers. These views from the Mendoza Codex illustrate the role of night-time observations in timekeeping. (Kingsborough, 1831)

the astronomy of the Classical World is not even hinted at. Instead, the hierarchical structure of the system becomes the basic theme of the picture.

The current cosmology of the Lacandon, among the few remaining survivors of the original Lowland Maya with their religion still somewhat intact, is strongly reminiscent of this layered-universe concept. Informants say that above the several layers of heaven occupied by various members of the Maya pantheon are three separate zones allocated to the sun, the moon, and the stars.

The statement about Netzahualpilli also reflects something more than a casual interest in celestial events. The astrologer-king was obviously engaged in some sort of celestial measurement. Torquemada has not provided us with enough detail to shed light on the methodology for gauging the stars. But if we look at the Central Mexican codices we find a number of pictures which serve to illuminate our understanding of the techniques and objectives of practical astronomy in Mesoamerica. The Codex Mendocino, or Mendoza (1831), a picture book produced shortly after the conquest, tells about various aspects of the lives of certain members of the Aztec noble class. Pictures (a), (b), and (c) of Fig. 4, taken from the Mendoza, contain adjoining captions written in Spanish. In picture 4a we learn about the primary role of the astronomer. The seated priest is "watching the stars at night in order to know the hour, this being his official duty." An inverted hemisphere studded with stars, symbolized by half-shut eyes, hangs over his head. In picture 4b, which appears adjacent to 4a in the Mendoza, another priest is beating on the *teponaztli*, to announce the time of night as determined from the observations of the first priest. Picture 4c informs the reader that the time of night is recognized as suitable for the performance of an obvious agricultural function. These drawings emphasize the utilitarian role of night-time skywatching. We have no evidence of

the use of water clocks or any other mechanical timekeeping devices in Mesoamerica. The celestial cycles seem to have been sufficient for marking the passage of time.

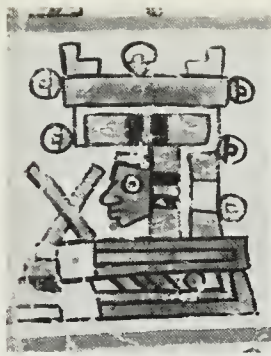
Other codices are more specific. Another series of pictures suggests that certain temples, in particular their doorways, were used as sighting stations to observe astronomical events at the local horizon (Fig. 5). In 1906, anthropologist Zelia Nuttall first proposed that the pair of crossed-sticks so prominent in many of the codices may have functioned as a sighting device. In Fig. 5*a*, from the Bodleian manuscript, we see a priest situated in a chamber within his temple. He peers out the doorway over a pair of crossed-sticks as if to mark the place of an astronomical event on the horizon. The outside of his temple is studded with star symbols, suggesting that it may have functioned as an astronomical observatory. Is the stick actually a measuring device? What horizon event is being witnessed? Does the star temple have a special orientation toward the object on the horizon?

Using a pair of notched-sticks, one as a foresight and the other as a backsight, an observer can determine the position of an object near the horizon with great accuracy, as we shall see in Chapter III. The sticks could be set in fixed locations to record the position of an astronomical body. When the body returned to its position between the notches, the astronomer could determine the length of its cycle. Perhaps a prominent feature in the landscape functioned as a natural foresight. In either case, the observatory edifice would have to be preferentially oriented so that it faced that part of the landscape where the event occurred.

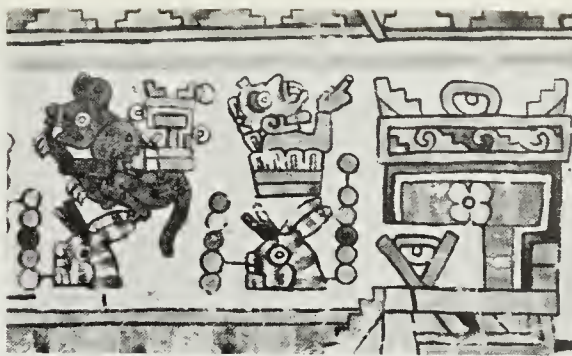
We have no way of knowing whether the sticks were true measuring devices capable of giving angular measurements of, say, the separation of a pair of celestial objects or if they were intended simply as a guide to the observer in performing a ritual operation in connection with the object in question. We know that the observation of the rising and setting of certain celestial bodies was of extreme importance in Mesoamerica. Since these events take place along the horizon, we can make a strong connection between our priest and the horizon events.

Mary Elizabeth Smith (1973*a,b*) has studied "place signs" in the Mixtec codices. These books also tell of the adventure and exploits of members of the noble class. Often they confront places of worship where astronomical temples exist. Smith concludes that the "observatory place" referred to in the Bodley Codex was located in the city of Tlaxiaco. The eye and stick symbol, in fact, is equivalent to the Mixtec name of that city, which is given in the old dictionaries as *ndisi nuu*. This can be translated as "clearly seen" or "clearly visible"—an obvious reference to the location of the observatory.

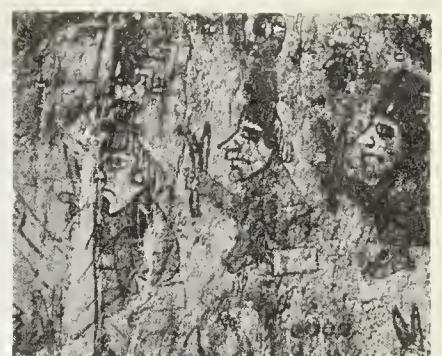
As further support for this idea, Smith cites page 2 of the Codex Muro where there is shown a figure seated in a temple marked by his calendric name-day in the 260-day calendar. Above his name appears a sign consisting of an eye embedded in a flame resting on a bowl. The Mixtec gloss accompanying the drawing indicates that the person's name includes the phrase *ndisi nuu*. This eye motif in Muro is identical to the eye seen between two sticks placed on crossed legs in the "observatory" sign, and thus it seems likely that "observatory" is the



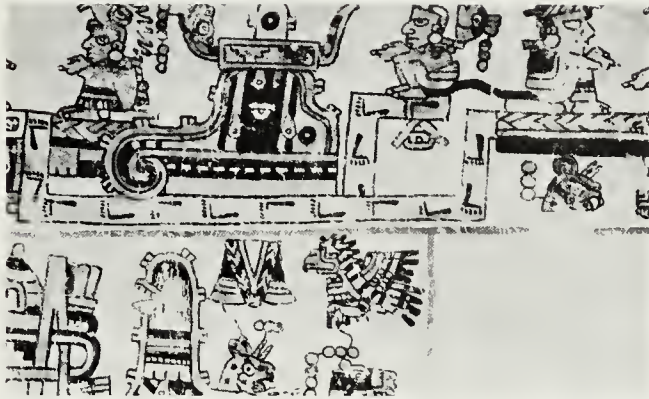
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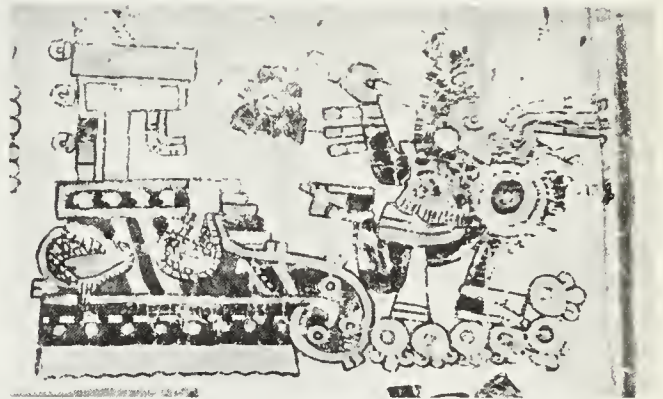
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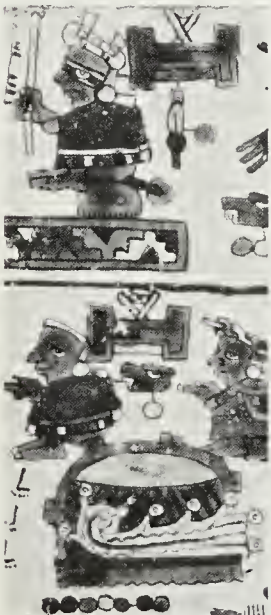
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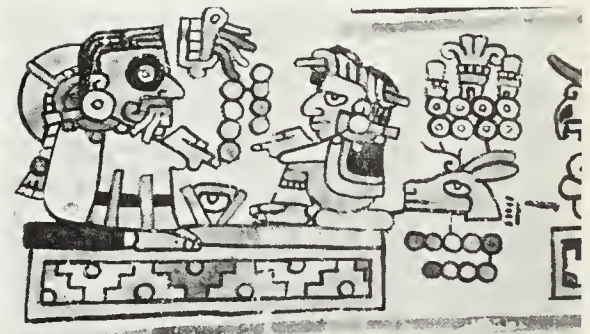
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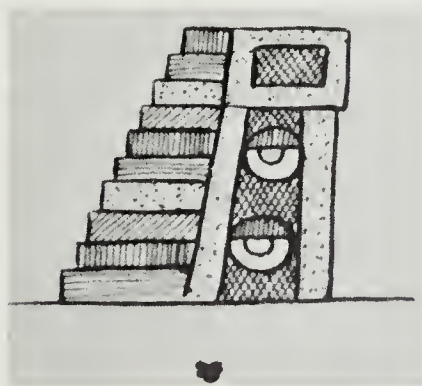
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h



i



j

FIG. 5. Crossed-stick sighting devices pictured in the bark-painted codices (Bodley, Selden, and Fernández Leal) and in the Lienzo of Zacatepec No. 1. (a, b, d, e, f, g, and h courtesy of Akad. Druck-u. Verlag, Graz)

sign of *ndisi nuu*, or Tlaxiaco. The eye-stick symbolism is repeated in the other pictures in Fig. 5, which are sampled from various codices. In 5*b* the eye is placed over the stick and the observatory is reproduced again in miniature on the back of the animal at the left, while 5*c* shows some sort of hand-held device being employed by seated individuals. In 5*d*, also from the Bodley, an eye appears in a doorway and to the right we see an inverted eye implanted into the notch of a pair of inverted crossed-sticks. Here, according to Alfonso Caso (1960), the man 3 Dog, son of 4 House and 5 House, journeys to the hill of the serpent, represented by the building with the eye at the center. But no mention is made of the inverted crossed-stick. In 5*e* 13 Eagle makes war on 8 Jaguar, the man of the observatory. The eye and stick, nearly effaced, rest atop the building and, again, the structure is star studded. The eye and stick are connected with a ballcourt in 5*f*, the latter being symbolized by the capital-I-shaped configuration located on the same wall. Since Mesoamerican ballcourts possessed ceremonial as well as astronomical significance, it is possible that the "Tlachtli-instrumento astronomico" ("ballcourt instrument") identified by Caso was used to orient the structure. The magnificent ballcourt at Xochicalco is, indeed, oriented to within a few minutes of arc of the east-west direction. Here the sun rises and sets at the equinoxes, when days and nights are of equal length. The ceremonial ball game is well known to any visitor to the ruins of Copán, Chichén Itzá, or Monte Albán. The hard rubber ball driven back and forth along the ballcourt symbolized the cyclic motion of the celestial luminaries. As we shall see later, the game was also represented as the celestial ballcourt in constellation form. The astronomer of Fig. 5*g* wears the sign of his occupation as a headdress. (Or can we assume that the man comes from Tlaxiaco?) Picture 5*h* is one of several in which a pair of figures appears to be engaged in conversation on opposite sides of the eye-and-stick symbol. Two "stars" gaze out of a shaft in the side of a building shown in profile in 5*i*.

Fig. 5*j* is taken from a section of the Lienzo of Zacatepec (no. 1), a woven cotton cloth illustrated with black ink found in the town of Santa María Zacatepec, Oaxaca (see Smith 1973*a*, chap. 7). This time the entire head of a man is placed at the junction of a pair of sticks making the shape of an "X." To the right the exaggerated eye symbol above a spider weblike device appears beneath the face of a man.

Another astronomical instrument may be embodied in the year glyph, particularly as it is displayed at Xochicalco and Teotenango (Fig. 6). A. Digby (1974) of the British Museum believes the glyph represents a device which consists of a pair of crossed trapezes mounted on a circular plate used to observe the sun in the manner of a classical sundial. His conception of such a device is reproduced in Fig. 6. The right-angle intersection between the crossbars casts a moving shadow on the plate, the shadow taking different paths on different days of the year.

While the similarity between the year glyph and Digby's three-dimensional device is undeniable, there is little supporting evidence that such an instrument was actually employed to measure the time of day or year (though the one he has constructed certainly works).

The pictures in Fig. 7 refer to still other possible sighting schemes and devices. In the first four of these, a pair of crossed-legs seems to

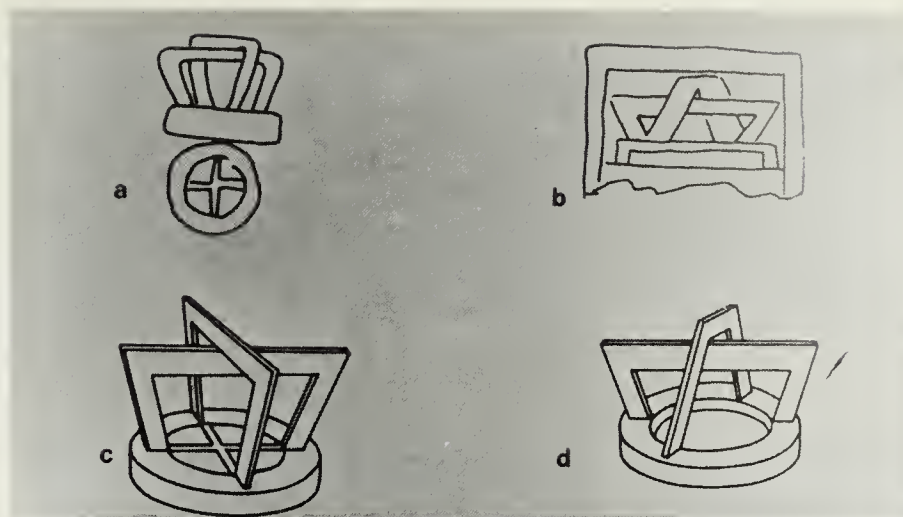
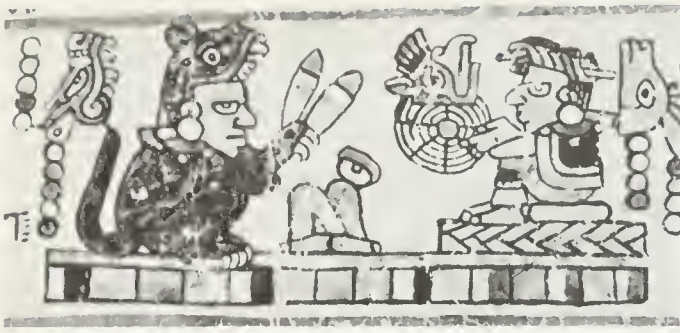


FIG. 6. *Top*, year glyphs on (a) the Temple of the Plumed Serpents at Xochicalco and (b) a stone at Teotenango; *bottom*, A. Digby's reconstruction of these as sundials. (Digby, 1974, p. 273; courtesy of Gerald Duckworth & Co. Ltd.)

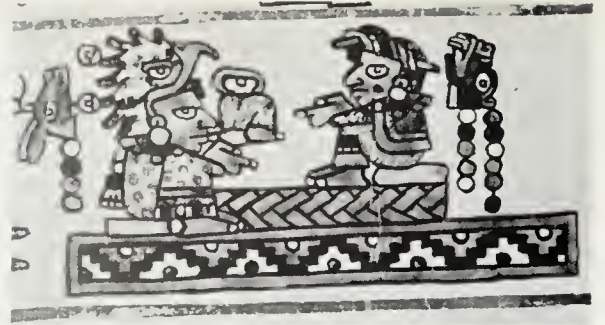
function in the same manner as the sticks. (As we shall see in our discussion of the Maya calendar, the crossed-legs hieroglyph plays a role in the delineation of time in their cosmology.) The knee sign appears in the same kind of (stellar) temple in 7c as that which housed the priest with the sticks in Fig. 5a. Smith (1973a) states that the word *dzichi*, meaning legs, is being substituted for the homonym *ndisi* in the name of Tlaxiaco, while Nuttall (1906) suggests that the stars were literally sighted over the legs from a reclining position on certain ritual occasions. Both crossed-legs and crossed-sticks appear in picture 7d. In 7e through 7h the priests hold scepters in their hands. Stars are positioned on the tips or in-between. One of the three-pronged sighting devices is carved in low relief on the side of Building J, a well-known astronomical observatory (see Chapter V).

Given both the hypothetical Digby instrument and the many references to the eye-stick symbolism, we have exhausted all the evidence relating to Mesoamerican astronomical instrumentation. No artifacts of measuring instruments survive and few statements in the ethnohistoric record allude substantially to the practice of measurement. We must face the fact that any accuracy attained in Mesoamerican calendar and building orientation was accomplished without the use of calibrated devices. At least the contemporary evidence points us in that direction.

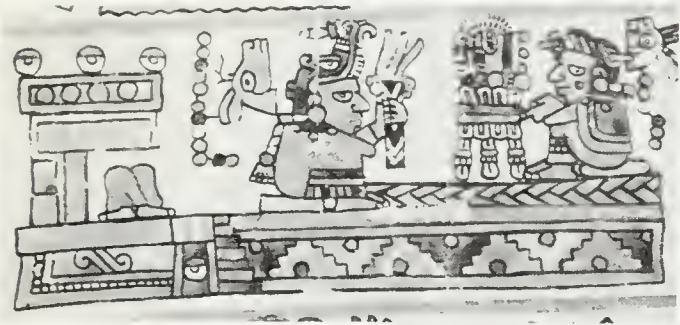
In many cases throughout the Bodley Codex, the story tells of offering and sacrifice performed at the building, or buildings, called "observatory." Never are we told what these priests are observing. But we can look to other pictures of star temples in the Vienna Codex (1974) for possible clues. In Fig. 8a we see a single star in the doorway of a temple appearing on a mountaintop. In the Vienna Codex, or Vindobonensis, this picture often occurs alongside three other temples, which Caso believes refer to the cardinal directions, the present exam-



a



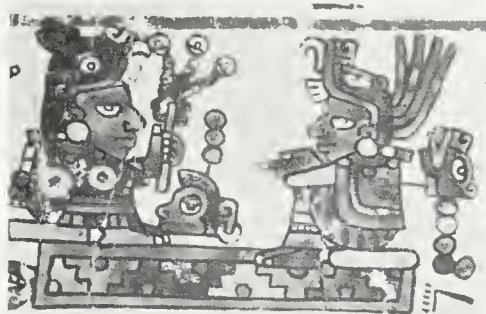
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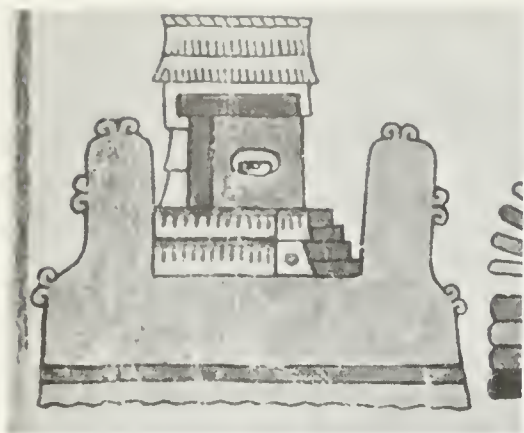
h

FIG. 7. Other sighting methods suggested in the Bodley and Selden codices: the crossed-legs metaphor and a pronged implement with stars perched on it. (Courtesy of Akad. Druck-u. Verlag, Graz)

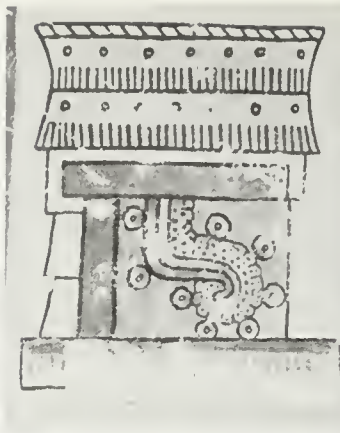
ple representing east. This direction may have been determined by watching for a particular star appearing above the horizon in that direction. Smith (1973*b*, p. 84) cites glosses from the Mixtec codices that refer to horizon observations, for example, "the horizon with the Pleiades at the zenith" (*tnono* = horizon; *yucu* = Pleiades; *dzini* = zenith). In Fig. 8*b* the celestial reference seems to be a particular constellation, a curved configuration looking like the tail of a serpent. Bernardino de Sahagún (1950), a sixteenth-century Spanish missionary writing shortly after the conquest, refers specifically to a constellation having this shape in the Florentine Codex (1950–1970). He calls it the tail of the scorpion (see Fig. 10).

Figs. 8*c*, *d*, and *e* refer to the sun. J. L. Furst (1978) has recently given a full interpretation of solar events in the mythic context occurring in the Vienna. In 8*c* we see the sun rising in the doorway of the Temple of the Sun. The place where the sun rises and the sacrifices are practiced is depicted in 8*d*, the sun in this case appearing on a mountaintop, while 8*e* displays the solar disk in the upper portion of the picture with the solar image personified by the warrior Tonatiuh carrying arrows in his hands. This signifies that the sun is a celestial warrior who, on rising in the east, throws his arrows, or rays of light, at the stars, thus ending the night and establishing the day. The lower disk shows the Mexican calendar day 1 Flower in the center, identifying the sun with an older god. The sun is thus shown twice: in the upper portion as being young when he is born in the east and in the lower portion when he is old, dying in the west. At the left of the picture, in both representations, day and night are equally represented though reversed on the sun disk symbol. At the lower left a road divided into four parts signifies the path of the sun through the four quarters of the sky. It may be noteworthy that in the last two cases the sun is referred to a place on the horizon, namely, at the top of a hill. The light-dark theme of this picture has also been interpreted as eclipse imagery (D. Kelley, private communication).

Caso (1950) believes that Venus is the celestial object displayed in Figs. 8*f* through 8*i*; this seems logical in the last picture since Quetzalcóatl, the Venus God, is shown supporting upon his shoulders a sky studded with these symbols. But Nuttall (1906) suggests that 8*j* through 8*m* also represent Venus. Here it is displayed most often with a pair of "wing-like appendages representing its radiance or light, the intention being to depict the planet at its period of greatest brilliancy" (p. 296). In 8*j* and 8*k* the image appears in a temple doorway. The astronomical nature of the temple in 8*j* is exemplified by the stars which adorn its rooftop. The Venus sign appears on the east wall of a ballcourt in 8*l*, exactly where the eye and stick convention was located in Fig. 5*f*. In 8*m* we have Venus minus its winglike appendages depicted at a period of lesser brilliancy, according to Nuttall. A figure (ball with dotted matrix) bearing a strong resemblance to this symbol appears in the Florentine codex (Fig. 10) where it is labeled "Venus, the morning star." This document may have inspired Nuttall to equate the two. But compare Caso's (1950) commentary on Fig. 8*m*: he identifies it as an altar of burning copal, or a place of self-sacrifice. Thus, he interprets the



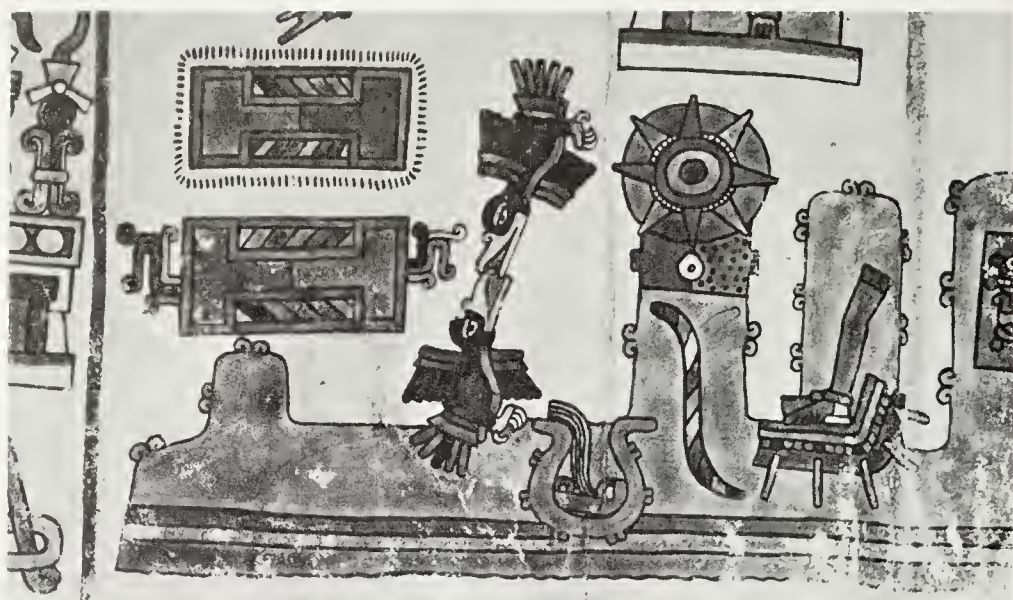
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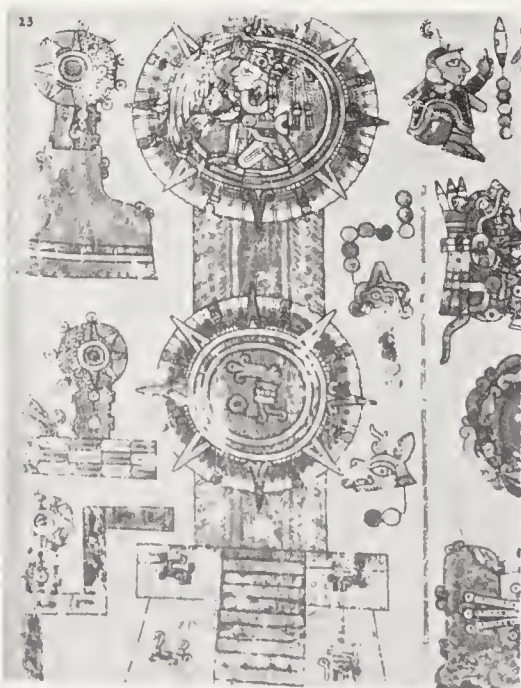
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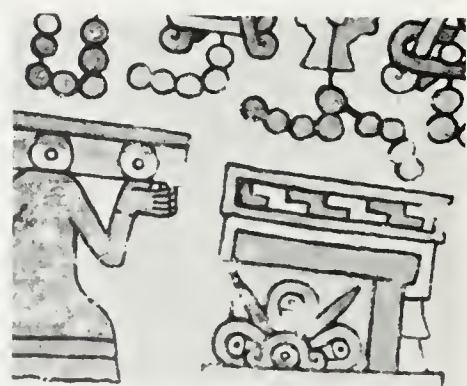
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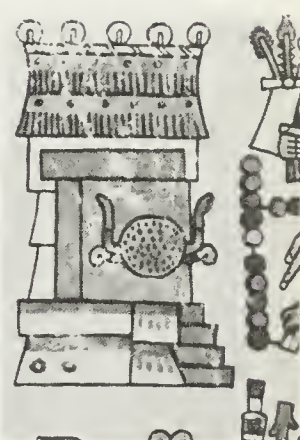
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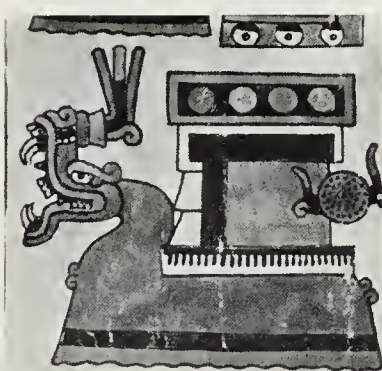
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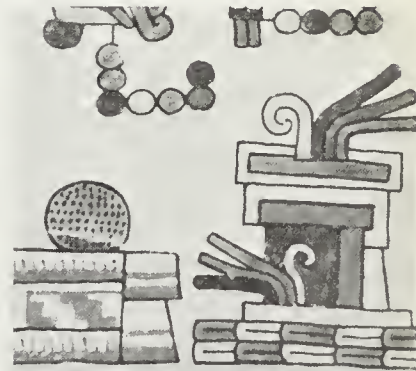
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m

FIG. 8. Specific astronomical bodies referred to in the Vienna Codex: (a) star, (b) serpent's tail (constellation?), (c)–(e) sun, (f)–(m) Venus. (Courtesy of Akad. Druck-u. Verlag, Graz)

same symbol with the winged appendages to represent a piece of burning copal incense.

We should not be surprised to find Venus references in the codices, but they also occur in postconquest documents. One of these was produced by Sahagún. It is entitled the *General History of the Things of New Spain* (known commonly as the Florentine Codex). Of all the celestial bodies observed by the Mesoamericans, Venus was among those of greatest importance. Called the Great or Ancient Star and Lord of the Dawn, "it became brilliant and shone white; like the moon's rays, so did it shine," says Sahagún (1953, pp. 11–12). "Captives were slain when it emerged that it might be nourished. They sprinkled blood toward it, flipping the middle finger from the thumb; they cast the blood as an offering" (p. 12). Augustinian monk J. Román y Zamora says of the Central Mexicans that "so accurately did they keep the record of the days when it appeared and disappeared that they never made a mistake" (Seler, 1904c, p. 358).

The alleged precision is revealed on pages 46 to 50 of the Dresden Codex of the Maya (1976), where we have a complete record of the apparition of Venus as morning and evening star. These pages, which are somewhat more abstract and sophisticated than the pictures presented in this chapter, will be analyzed in some detail in Chapter IV on the Mesoamerican calendar. In the dot-and-bar mathematical symbolism of the Maya, several "Venus years" are recorded in that document. They represent the interval between successive initial appearances of the planet as morning star. The 584-day period is broken down into four subintervals representing the length of time Venus appeared as morning star and as evening star; the disappearance intervals in-between are also recorded. An added page of the Dresden was fashioned to serve as a table of corrections to alter the Venus observations to a later time. Pictures accompanying the tables show the Venus god, Kukulcan, the Maya equivalent of Quetzalcóatl, in several evil manifestations, spearing his victims. Evidently, the reappearance of Venus in different quarters after a prolonged absence carried various evil connotations for the people of Yucatán. Sahagún (1950) tells us that, when the morning star rose, people stopped up their chimneys so that no harm from its light could get into their houses. Obviously, they were deeply concerned about where and when Venus might appear to reverse their fortunes.

The codex pictures in Fig. 9 refer to other celestial events of importance in Mesoamerica. Fig. 9a depicts the great solar eclipse of A.D. 1496 (August 8), total in Central Mexico. It is represented in a combination of European and indigenous styles in the Codex Telleriano-Remensis (1899). Later in this same document, the solar eclipse of A.D. 1531 is represented (Fig. 9b). The same eclipse is pictured in 9c from the Codex Vaticanus (1972), which document also shows other eclipse representations, for example, 9d, in which, curiously, the eclipse is pictured as taking place on the horizon.

In Book VII of the Florentine Codex (1950–1970) we sense the fear of the Aztecs upon witnessing the dramatic event of a total eclipse of the sun:

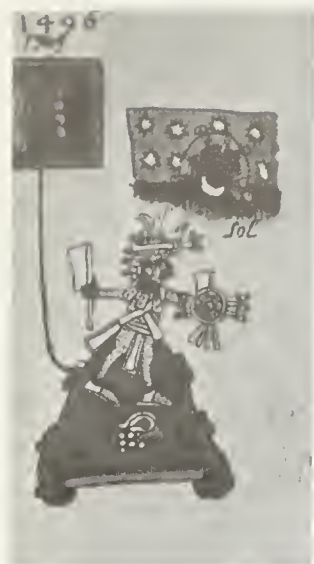
When this came to pass he [the sun] turned red; he became restless and troubled; he faltered and became yellow. Then there were a tumult and disorder. All were disquieted, unnerved, frightened. Then there was weeping. The common folk raised a cup, lifting their voices, making a great din, calling out, shrieking. There was shouting everywhere. People of light complexion were slain [as sacrifices]; captives were killed. All offered their blood; they drew straws through the lobes of their ears, which had been pierced. And in all the temples there was the singing of fitting chants; there was an uproar; there were war cries. It was thus said: "If the eclipse of the sun is complete, it will be dark forever! The demons of darkness will come down; they will eat men!" (Sahagún, 1953, p. 12)

An eclipse of the sun and an eclipse of the moon are pictured in the Florentine Codex (Fig. 10). Evidently, the Aztecs were every bit as frightened of the latter phenomenon:

When the moon was eclipsed, his face grew dark and sooty; blackness and darkness spread. When this came to pass, women with child feared evil; they thought it portentous; they were terrified [lest], perchance, their [unborn] children might be changed into mice; each of their children might turn into a mouse.

And because they feared evil, in order to protect themselves, in order that this might not befall [them], they placed obsidian in their mouths or in their bosoms, because with this their children would not be born with mouths eaten away—lipless, or they would not be born with noses eaten away or broken off; or with twisted mouths or lips; or cross-eyed, squint-eyed, or with shrunken eyes; nor would they be born monstrous or imperfect. (Sahagún, 1953, pp. 8, 10)

Comets (*citlalimpopoca*, or the stars that smoke) are represented frequently in the surviving historical documents, usually by a stellar image on a blue background with emanating streams of smoke: Figs. 9e and f from Codex Vaticanus and 9g from Codex Telleriano-Remensis. These usually signify that a person of nobility will die; for example, picture 9e tells of the death of the ruler of Tenochtitlán following the apparition of a comet; later another comet occurs, then an earthquake, all of nature's events being connected in the Aztec cosmic view. The caption in 9h tells us that the star Venus is smoking. It is curious that, in this case, reference is being made to an image which appears slightly different from the usual representation of a comet. Perhaps a cometary object appeared near the planet. In 9i from Codex Telleriano-Remensis and 9j from Codex Vaticanus, the celestial reference may be a meteor or "shooting star." Of the animal wounded by the "shooting star" Sahagún says, "It hath received a worm—and was not to be eaten." Also, "by night all were well protected. All covered themselves, wrapped themselves in mantles and bound on their garments for fear of the shooting star" (1953, p. 13).



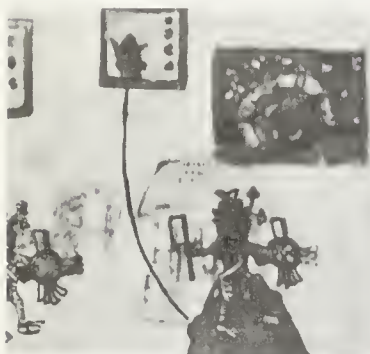
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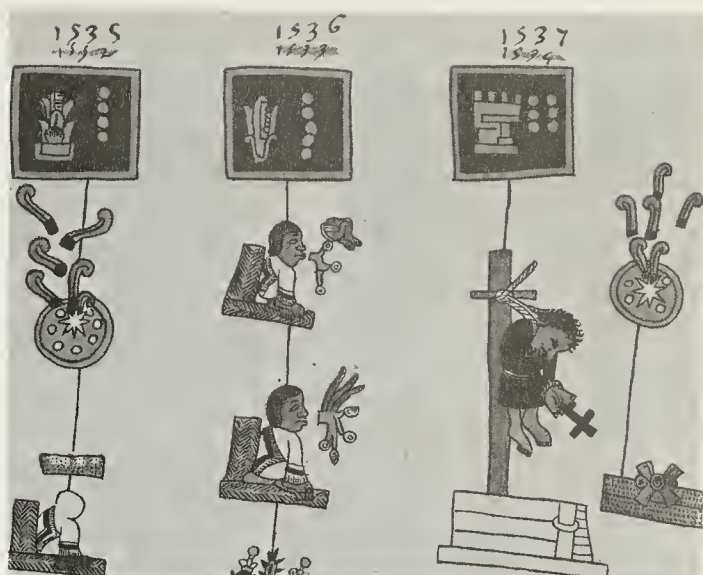


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FIG. 9. Additional astronomical records in the postconquest Codex Telleriano-Remensis and Codex Vaticanus. Note the Hispanic flavor of some of the pictures as compared with the preconquest drawings of FIG. 7. (Courtesy of Akad. Druck-u. Verlag, Graz)



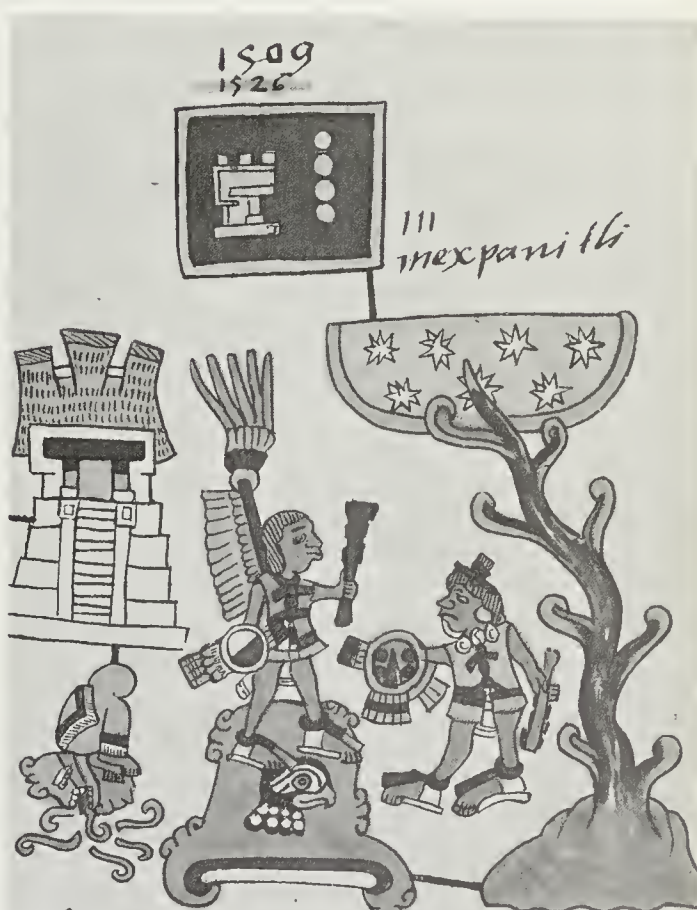
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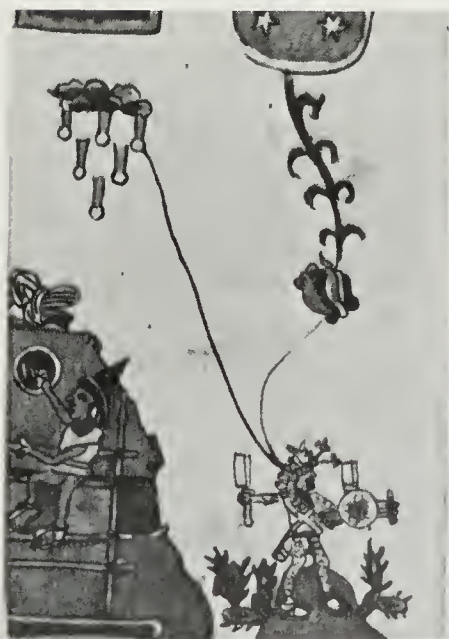


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One of the problems of identifying the celestial percepts of vanished cultures is that we often make too many assumptions about what those people must have seen. Constellations or star patterns on the sky are derived as much from cultural tradition as from visual perception. While some celestial groupings (e.g., Orion's Belt and the Pleiades) might be universal, too often we force our own heavenly dippers and zodiacal signs upon a culture with little other supporting evidence. (For an excellent discussion of this problem, see Urton, 1978a, pp. 5-15.)

Foremost among the star groups accorded a place of prominence throughout Mesoamerica are the celebrated Pleiades, or Seven Sisters of the Classical World. This star group has been of such great importance to nearly every developing civilization that a digression of Pleiades observations in general may be worthwhile.

In his monumental work on myth, *The Golden Bough*, Frazer (1936-1937) lists page after page of documentation alluding to Pleiades observations among North, Central, and South American people, Africans, Polynesians, Australians, and even the people of Kamchatka, far north of the tropics. Nearly all these people observed the appearance and disappearance of this conspicuous group of stars to time the commencement of certain operations in the agricultural calendar. The Guaranis of Paraguay date the beginning of their year and time the sowing of their seed by the heliacal rising, or first annual predawn appearance, of the Pleiades in May (see Chapter III, Appendix B and n.16). For the tribes in Matto Grosso in the Amazon valley, the first appearance of the Pleiades signals the beginning of the rainy season and the migration of the birds: "While it is low, the birds and especially the fowls sleep on the lower branches or perches, and just as it rises so do they; it brings much cold and rain; when it vanishes serpents lose their venom; the reeds used in making arrows must be cut before the appearance of the Pleiades, else they will be worm-eaten" (Frazer 1936-1937, 1:309). The Blackfeet in North America use these stars to regulate their most important feast, which includes, in addition to a pair of sacred vigils to wait for their arrival, the blessing and the planting of the seed.

In the Society Islands in the South Pacific, the year is split into two seasons which are determined by the heliacal (see Appendix A, Chapter III) rising and setting of the Pleiades. The Sherente of Brazil employ the same concept, thereby creating a calendar which is even more complicated. According to Lévi-Strauss: "The year begins in June with the appearance of the Pleiades when the sun leaves Taurus. When these stars appear it is believed to be a sign of wind. Their heliacal rising is observed. Between two such risings they count 13 months and divide the year into two parts (four moons dry weather June-Sept., nine moons rain Sept.-May). In the first two dry months large trees of a piece of forest land are felled to free it for cultivation. In the following two months the ground is cleared by burning scrub" (1964, p. 217).

Among primitive societies, the Pleiades are often the only celestial group paid any attention. In Bali, the Pleiades and Orion's Belt are the only stars the people use to correct their lunar calendar. They

bring the lunar year (12 months of $29\frac{1}{2}$ days = 354 days) into harmony with the tropical year by prolonging one of their months until the Pleiades become visible at sunset. The Caffres of South Africa regulate the lunar year as well as the agricultural calendar by the Pleiades. Any confusion about the solar year is always set right by their heliacal rise, and things function normally until "the moons get out of place, and reference has again to be made to these stars" (Frazer, 1936-1937, 1:316).

The Pleiades are also worshipped among aboriginal people who do not practice agriculture. This may be due to the coincidence of the first annual appearance of the group at the beginning of the rainy season. Developing civilizations could hardly fail to observe that wild fruits grew more plentifully and therefore that they would have more to eat after a heavy fall of rain than after a long drought. Hunters could learn of the migration of their prey as a function of the meteorological cycle. It would then be but a simple step to attribute the cause of certain terrestrial occurrences to these stars. Indeed, many of the aboriginal people of Australia regard the Pleiades not merely as a signal but instead as the cause of rain—an astrological rather than an astronomical function. They curse the Pleiades if their appearance in the sky is not immediately followed by a rainy period.

We might expect that any people who would strongly attach world affairs to the appearance and disappearance of the stars would also worship them with equal intensity. Among the Mocobis of Peru and the Navaho of Arizona, the Pleiades are both father and creator. Their image adorns the forehead of Black God, the principal Navaho deity. The Guaycurus of the Gran Chaco flayed one another upon their appearance so that they could be blessed with good health, good crops, and success in war.

The Pueblos begin a sacred nocturnal ritual when the Pleiades rise. According to Jesse Fewkes (1895), indefatigable archaeologist-explorer of the Southwestern United States at the turn of the century, an invocation was made to the gods who represented the quarters of the world. He concludes with the statement: "I cannot explain its significance, and why of all stellar objects this minute cluster of stars of a low magnitude is more important than other stellar groups is not clear to me" (p. 453).

Actually, the Pleiades are as easy to recognize as the brightest stars in the sky. Though each individual member is not bright, their combined light spreads over a considerable area of the sky resulting in an impressive phenomenon, easily recognizable by anyone who casually looks skyward.

The Pleiades, then, probably owe their prominence in myth and folklore to a combination of their conspicuousness in the heavens and the coincidence of their appearance and disappearance on either side of the sun during significant periods in the seasonal calendar. In Chapter III we will discuss the mechanics of the Pleiades' motion. As we shall demonstrate, their occurrence close to the ecliptic offers some exactitude in the timing of heliacal rise and set.

The foregoing statements represent but a fraction of the ethnohistorical evidence pertaining to the observation of a single star group.

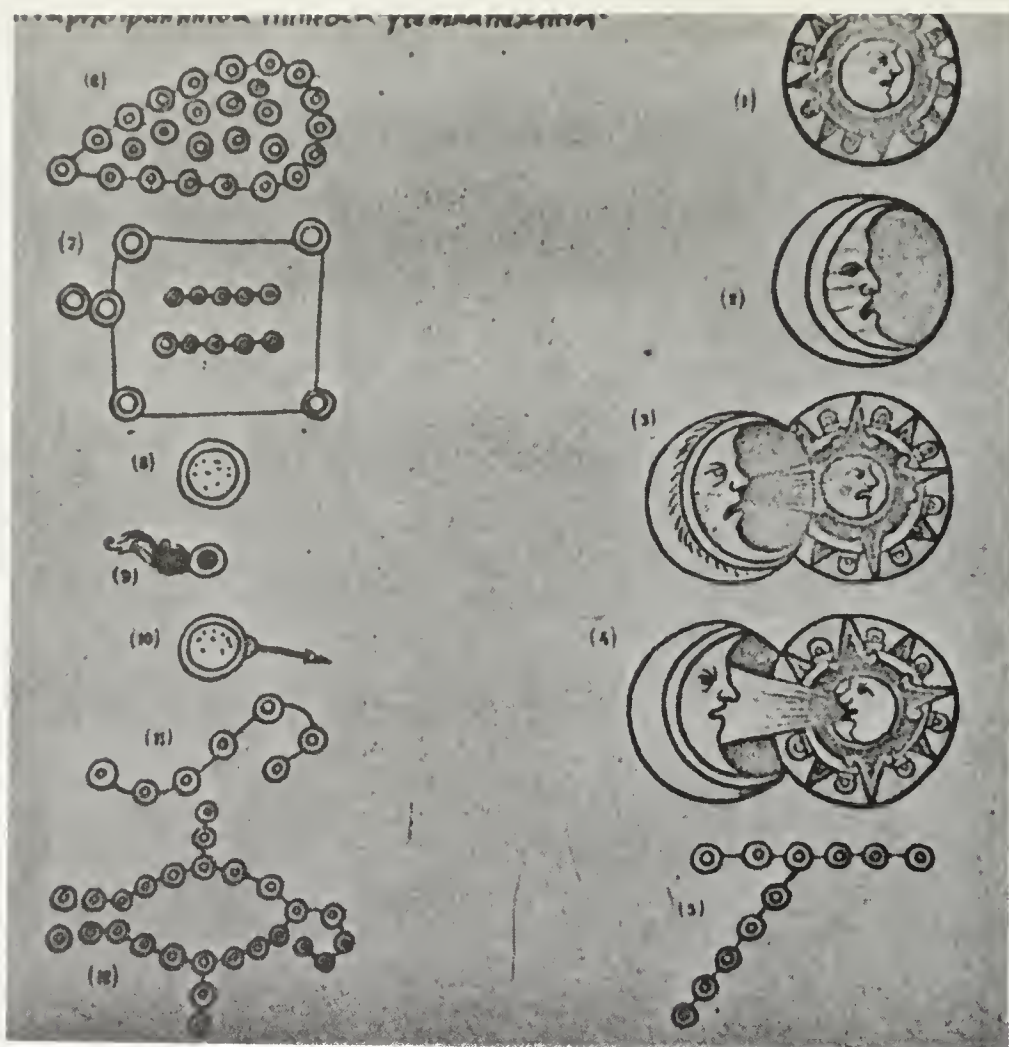


FIG. 10. Astronomy in the Florentine Codex of Sahagún: *left col.*, Tianquiztli, or market place (the Pleiades), Citlaltlactli, or ballcourt (Gemini?), Citlalpol (Venus), Citlalpopoca, or smoking star (comet), Citlaltlamina (shooting star), Xonecuilli (Little Dipper?), Citlalcolotl (Scorpio?); *right col.*, Tonatiuh (sun), Meztli (moon), solar eclipse, lunar eclipse, Mamalhuaztli (Orion's Belt and sword?). (Sahagún, 1953, fig. 21; courtesy of School of American Research and University of Utah Press)

They serve to illustrate a deep and widespread bond between humans and cosmos in all developing civilizations.

The seventh chapter of the Florentine Codex, "Which Treats the Natural Astrology Attained by These Natives of This New Spain," gives a written and pictorial account of certain Aztec constellations (see Fig. 10). The manner of representing the stars as circles connected by lines is reminiscent of the constellation patterns which can be seen inscribed about the periphery of the Aztec calendar stone. At least one pattern, called the tail of the scorpion, is common to both (compare Fig. 11).

There has been some confusion over the attempted identification of these patterns with modern constellations (see Fig. 12); neverthe-



FIG. 11. The dotted patterns pecked into the edge of the Aztec calendar stone may represent constellations. The identification of Xoneciulli at the top is unmistakable, that of the others far less certain. In one case (Citlaltlactli?) the stars are connected by lines as in the Florentine Codex (cf. FIG. 10). Is Citlalcolotl the group above this configuration? (Nuttall, 1901, fig. 56)

less, a few conclusions can be agreed upon. The constellation of Tianquiztli (so labeled in Fig. 10) surely represents the Pleiades. The Aztecs determined the occurrence of their most important feast day by the appearance of the Pleiades, which marked the fifth cardinal point. According to Sahagún (1953), the ceremony of the Binding of the Years took place every 52 years¹ and began when the Pleiades crossed the overhead position at midnight (about mid-November), a statement which suggests the Aztecs were marking the time of night. When the time approached, the priests ascended the Hill of the Star to watch the movement of the Pleiades with great anxiety: "And when they saw that they had now passed the zenith, they knew that the movements of the heavens had not ceased and that the end of the world was not then, but that they would have another 52 years, assured that the world would not come to an end" (Sahagún, 1957, p. 143). Broda (1979b) has tied these observations to a method for fixing the months of the Aztec calendar. Smith's (1973b, p. 84) translation of a Mixtec phrase on page seven of the Codex Muro as "the horizon [with] the Pleiades at the zenith," might be kept in mind here.

Although the arrowlike configuration representing them in the Florentine bears little resemblance to the Pleiades at first glance, the clustering of the nine stars inside the connected chain representing the outer boundary of the constellation bears a distinct resemblance to the Pleiades as they appear in the sky, as the enlargement of the group in Fig. 12 attests. Though we see only six or seven Pleiades without a

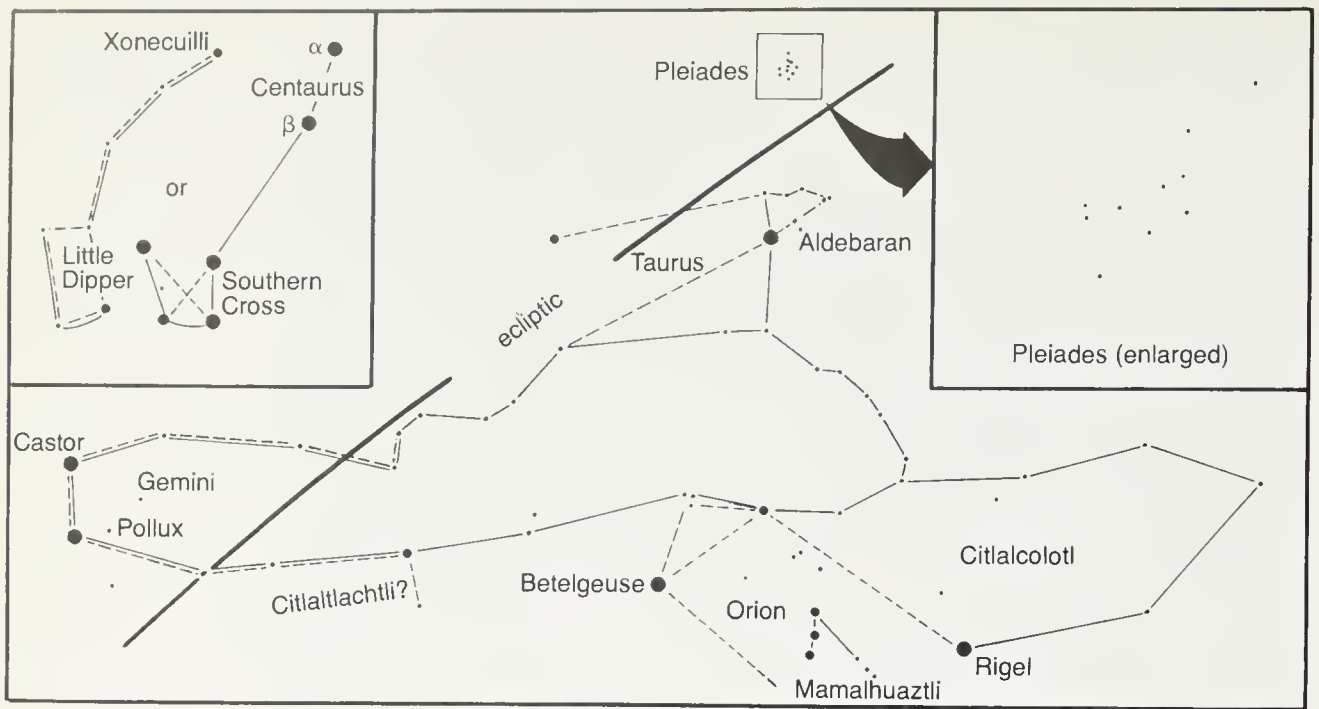


FIG. 12. Aztec and Western star patterns contrasted. In this winter sky scene, solid connecting lines form the constellations as the Aztecs imagined them. Dashed lines depict our modern versions. Some groups, like Orion's Belt (Mamalhuaztli) and the Pleiades (*enlarged at the upper right*), seem to be recognized universally. The Serpent's Tail constellation (*upper-left enlargement*) fits either our Little Dipper or the Southern Cross with Alpha and Beta of Centauri added. (Diagram by P. Dunham)

telescope in the northern latitudes, under clear sky conditions at high altitudes where the atmosphere is relatively tenuous the discerning eye may witness a few additional stars, especially when the group transits the zenith. As we shall see in Chapter V, these stars, above all others, may have had a direct influence on the orientation of ceremonial centers.

Today among the Chorti Maya of Guatemala the Pleiades, called "El Siete Cabrillas," or "Seven Kids," fix the day of the planting and the coming of the rains when they undergo heliacal rising in the morning sky on April 25. It is at this time that they announce the first annual passage of the sun across the zenith, a phenomenon said to be responsible for the fertilization of the seeds. "Rites and ceremonies are held in order to celebrate this fact" (Girard, 1948, p. 67). Among the ancient Maya the Pleiades were called *tzab*, "the rattlesnake's tail," a form by which this hieroglyphic representation is recognized at several places in the codices (Dütting, 1979).

The constellation of Mamalhuaztli, the "Fire Drill" or "Fire Sticks," is also labeled in Fig. 10 and may be represented on the periphery of the Aztec calendar stone by a pair of intersecting straight lines composed of stars.

They name these stars *Mamalhuaztli*, and by that same name they call the sticks with which they drill a fire, because it

seemeth to them that they somewhat resemble the stars and that from them there came to them this manner of producing fire. From this it was customary that the men make certain burns on the wrist in honor of those stars. They said of him who was not marked by those burns that, when he died, there in hell they would produce fire on his wrist, drilling it there as those do who here drill fire with the stick. (Sahagún, 1953, pp. 60, 62)

The ritual was carried out at the commencement of a 52-year cycle.

The same group is probably the one mentioned along with the Pleiades in an informative though somewhat confusing statement in the *Crónica mexicana*, written by the postconquest historian Alvarado Tezozomoc (1975). He gives an account of the formalities taking place upon the election of Moctezuma Xocoyotzin, king of the Aztecs. Following a long list of religious duties he is exhorted

... especially to make it his duty to rise at midnight and to look at the stars: at *yohualitqui mamalhuaztli*, as they call the keys of St. Peter among the stars in the firmament, at the *citlaltlach-tli*, the north and its wheel, at the *tianquiztli*, the Pleiades, and the *colotl ixayac*, the constellation of the Scorpion, which mark the four cardinal points in the sky. Toward morning he must also carefully observe the constellation *xonecuilli*, the "cross of St. Jacob," which appears in the southern sky in the direction of India and China; and he must carefully observe the morning star, which appears at dawn and is called *tlahuizcalpan teuctli*. (P. 574)

There is considerable confusion about the so-called Keys of St. Peter. According to Sahagún, they "walk in the area of the 'Siete Cabrilas.'" At this point we must be careful about accepting the old historians' descriptions as gospel. For example, Tezozomoc's discussion of ballcourts bears little resemblance to the game or the field on which it was played as we understand it from other sources. On medieval European maps the constellation of St. Peter included all of the zodiacal constellation of Aries and parts of Triangulum, Cetus, and Pisces; it was located immediately to the west of the Pleiades. The Keys seem to be composed of the faint stars 35, 39, and 41 Aries and 12 and 13 Triangulum. On the other hand, the editor of Tezozomoc's manuscript, J. M. Vigil, states that Alpha of Aries, 10° to the southwest of these stars and at the other end of the constellation, marked the location of the Keys. Even the most imaginative interpreter would have difficulty conjuring up a configuration similar to the Fire Drill shape shown in Fig. 10 out of stars in this area; however, an identification of the Fire Drill in the vicinity of Aries would put it on the ecliptic, a zone of celestial importance.

The Fire Drill constellation must be formed out of two rows of stars meeting at an acute angle. Both the Hyades group in Taurus and the Belt and Sword of Orion (bottom of Fig. 12) to the east of the Pleiades fulfill this condition and, accordingly, both have been suggested as possibilities. The latter seems more likely because Orion's Belt rose al-

most exactly at the east point, thus marking one of the cardinal directions which Moctezuma was supposed to watch. To solidify this argument, Michael Coe (1975, p. 26) notes that Sahagún refers to the group as the little sticks or little stars which, according to the native dictionaries, is synonymous with the name for Orion.

Because Sahagún never labeled it, we cannot be sure whether the box-shaped constellation in Fig. 10 represents Tezozomoc's Citlaltlactli, or the Star Ballcourt, also called the north and its wheel. Actually the grouping bears little resemblance to stars around the pole. The two parallel rows of stars representing Gemini the Twins have also been suggested as a possibility (left side of Fig. 12), though on appearance the identification seems weak. On the other hand, Sahagún tells us specifically that Gemini was important to the Aztecs:

These people paid particular reverence and (made) special sacrifices to Castor and Pollux, in the sky, which move near the Pleiades, which are in the sign of Taurus. They made these sacrifices and ceremonies when (the stars) newly appeared in the east after sunset. After having offered incense, they said: "Now (hath) *Yoaltecuhtli* come forth, and *Yacauiztli*. What will come to pass this night? Or what end will the night have—fortunate or adverse?" Three times they offered incense—the first time at the first quarter of the night, another time at ten, and the third (time) when it beginneth to be morning. (1953, p. 60)

The identity of the dipperlike configuration in the Florentine labeled "Xonecuilli" is also difficult. Though it resembles our Little Dipper, Tezozomoc places it in the southern part of the sky. There it can be identified with the Southern Cross (the four stars forming a square at the right side of the configuration) and a chain of bright stars in Centaurus, including Alpha and Beta of that modern constellation (see Fig. 12 for a sketch of the possibilities). It may be significant that, when Orion's Belt lay due west on the horizon in the skies of Central Mexico in A.D. 1500, the Southern Cross stood 15° above the horizon exactly over the south point. It is realistic to assume that the ancient Mexicans would place their key constellations at the cardinal points since the plans of their temples were often oriented this way. As we shall see when we discuss their calendars, the quadripartite division of the universe is central to any comprehension of Mesoamerican cosmology.

The Southern Cross has long been regarded as an important star group throughout Native America. It has been symbolized in the form of a mythical turkey-bird by the Warao people who live in Brazil, 9° south of the equator. According to anthropologist Johannes Wilbert (1973), a complicated Warao myth is associated with the orientation of this bird on the sky at different times. The basic astronomical elements emerging from the myth suggest that every evening at nine o'clock he rises in the southeast to fly to the meridian where one of his wings chants in order to protect all newborn females in the tribe. Old women of the tribe must chant back, encouraging the bird on his heavenly journey, lest he lose his feathers to his celestial pursuers, the hunters, who are represented by Alpha and Beta of Centaurus. He re-

turns at noon and later chants with his other wing, thereby protecting all the newborn males. Thus he is on the meridian at midnight for females and at noon for males. In the present context, it is interesting to note that Wilbert has traced the origin of the myth to the civilizations of Central Mexico or Yucatán (latitude 20° N, A.D. 1500) by duplicating in a planetarium the positioning of the Cross at different times with respect to related constellations, for example, the Northern Cross, as described in the Warao myth. He finds strong similarities between the cosmology of the Warao and that of the Aztecs and Maya.

An equally possible identification for Xonecuilli is the Big Dipper, which the pattern closely resembles, even down to the number of stars depicted. The bowl of the Dipper transited the celestial meridian of Tenochtitlán at the same time Orion's Belt set in the west; therefore, this obvious grouping could have served to mark the north cardinal point. But a *Little Dipper* designation (Fig. 12, inset at upper left) cannot be ruled out, especially since Sahagún specifically equates these stars with Xonecuilli (though they certainly are not as prominent as he indicates): "The stars which are in the Little Bear these people call Citlalxonecuilli. They represent them in the shape of an S, backwards (of) seven stars. They say they are by themselves, apart from the others, and that they are brilliant" (1953, p. 66). Only Polaris at one end and Kochab at the other end of the Dipper can be said to possess any brilliance, and they are of the second magnitude. The five stars in-between would hardly be prominent, especially at the low altitude attained by the Little Dipper in Mexico.

At the same time that Orion's Belt lay on the western horizon and the Southern Cross marked the south point, Antares, the brightest star of our constellation Scorpio, was in the opposite part of the heavens, rising 25° south of east. According to Coe (1975), both the ethnohistoric and the ethnological evidence strongly support the identification of the remaining Florentine constellation, Citlalcolotl, with Scorpio. The coiled tail at the right side of the figure is similar to the coiled tail of the modern constellation, but evidently the Aztecs saw the rest of the star group combined with portions of adjacent constellations in a different way, as Fig. 12 suggests. In the representation given there, Castor and Pollux are the mouth of the scorpion, Rigel the stinger at the tip of his tail. Since the region of our own Scorpio is crowded with stars of the Milky Way, identification of specific stars is impossible. As Coe stated: "Either this group naturally looks so much like a scorpion that it has received this name independently, or it was in some way diffused to the New World" (p. 26). A group of stars forming a rounded configuration visible on the Aztec calendar stone of Fig. 11 also may represent the scorpion. It is noteworthy that a number of the Sahaguntine constellations are situated close to the ecliptic. The patterns overlap with our zodiacal constellations: Gemini, Taurus, Scorpio. Our studies of the calendar in Chapter IV will reveal that the ancient Americans recognized a zodiac to mark the paths of the planets, though the constellation patterns comprising the zodiac were not identical to our own Western constellations.

✓ Individual stars were recognized by the Mesoamericans. Lamb (1979) has been compiling evidence from the Maya dictionaries relat-

ing to star and constellation names. Polaris, called Xaman Ek by the Maya, was universally used by travelers to find their way. Merchants were supposed to burn copal incense to the North Star by a roadside altar in order to be protected. Among the modern Lacandon Maya, Rigel and Sirius are Woodpeckers and Betelgeuse is Red Dragonfly. The bright stars in Gemini (still) represent a turtle and Orion's Belt is a peccary. To no surprise, the Pleiades, the Southern Cross, and the Big Dipper are also recognized. Venus is by far the most important planet (Baer and Baer, 1971).

Regardless of identification, the pictures of star groups in the codices emphasize the use of celestial bodies to indicate both time and direction. They also suggest a strong connection between astrology and astronomy. Celestial events are constantly linked to the rise and fall of various rulers, battles fought, and great disasters which occurred. Repeated reference to the observatory and its contents underlines the bond between astronomical observing and the calendar in Mesoamerican culture. Nuttall's study of astronomical pictures in the codices led her to conclude that "the ancient Mexicans not only employed their carefully oriented temples and ballcourts as astronomical observatories, but also invented ingenious devices for accurately registering the periodical appearances or disappearances of important bodies" (1906, p. 298).

But as far as the people were concerned, the observatory served a divinatory and ritualistic function more than an astronomical one. It linked the stars directly to their lives through omen and prophecy.

Our discussion of the interpretation of the Aztec stars and constellations also illustrates some of the difficulties associated with the study of ancient astronomy. To begin with, the historical record often can be confusing. The investigator must comprehend not only the workings of positional astronomy, but also the view of the cosmos as perceived by the priests of the Spanish renaissance who compiled most of the record available for study today.

When we attempt to identify stars and constellations with actual star patterns, we must be careful to avoid our own cultural bias. Our Western star maps usually display an accurate one-to-one representation of the positions of the stars, their magnitudes being represented by circles of proportionate diameters. The Aztec informant who drew the Tianquiztli star group in the Florentine Codex clearly did not utilize these ground rules when he encompassed his version of the Pleiades in a ringed star border with a point at one end.

The documentation of the astronomical knowledge of the Aztecs in the Florentine Codex reflects the cultural chauvinism of Sahagún. Though he lived and worked in Mexico for more than sixty years, he was a missionary whose primary function was to civilize and Catholicize the inhabitants of the land recently conquered by Spain. The questions he asked and the answers he interpreted were likely to be quite different from those emanating from a trained anthropologist. As Alfredo López Austin, who has studied the conquest period, puts it:

Sahagun asked about the nature of the sky with totally Occidental expectations, perhaps anticipating replies which might deal

with celestial spheres, the density of strata, universal rotation, the origin of temperature variation in attractions and repulsions of cold and heat, explanation of climates in different latitudes and altitudes, chronometry—all this and more constituting the celestial science of his time. His intentions, however, were confronted with an unexpected cultural barrier. If he attacks the Indians for their low level of understanding, they must have felt the same way about his intelligence when confronted with questions they considered ingenuous in their lack of knowledge. If Sahagún had understood something about the clash of ideas, perhaps his book would be one of the best sources on the cosmic vision of the Nahuas, discussing the upper to lower floors, the course of the stars through them, the supporting trees—information that is seldom available from other sources. (1974, p. 135)

We can now understand why Sahagún makes such frightening statements about the deleterious effects of celestial phenomena upon humankind, providing little information about native prediction and observation of the events alluded to.

Sahagún blames much of the avowed inaccuracy of his seventh chapter on the ignorance of his informants and the language problem:

The reader will have reason to be annoyed at the reading of this seventh book, and all the more so if he understands the language as well as the Spanish, because in Spanish the language gets very base, and the material touched on in this seventh book is very vulgarly treated. This is because the natives themselves related the things treated in this book in a vulgar fashion, the way they understand them, and in a vulgar language, and it was thus translated in Spanish in a vulgar style and with low level of understanding, pretending only to know and to write what they understood on this subject of astrology and natural philosophy, which is very little and very lowly. (Quoted from López Austin, 1974, p. 135)

Because the informants were most knowledgeable and talkative about the interpretation of the significance of astronomical events (the association of worming in animals with meteors or the fear that if a pregnant woman be exposed to a lunar eclipse her children would be turned into rats), Sahagún seems to have been content to collect and present this information.

But Durán gives a different reason for writing his chronicle (*The Book of the Gods and Rites and the Ancient Calendar*):

Thus we terminate our brief and condensed version of the calendar. I understand, I realize, that I could have enlarged the book and described more things in a detailed way, but my sole intention has been to give advice to my fellow men and to our priests regarding the necessity of destroying the heathen customs which they will encounter constantly, once they have received my warning. My desire is that no heathen way be concealed (hidden,

because the wound will grow rot and fester, with our feigned ignorance). Paganism must be torn up by the roots from the hearts of these frail people! (1971, p. 470)

Though we must be thankful for the storehouse of Aztec cultural concepts that Sahagún, Durán, and the other chroniclers have preserved for us, it is regrettable that so little is mentioned about how the Aztecs structured their universe and what tools they employed to watch it function. Astronomy, as it appears in the written record, was clearly not intended for the layperson, nor was it presented in the classical Greek tradition to be contemplated by philosophers for the sake of the betterment of their knowledge about the natural world. For the ancient Mesoamericans a vital cause-effect relationship existed between the events of daily life and motion in the heavens. The secret information was never intended to fall upon the ear of an outsider.

THE ETHNOGRAPHIC RECORD AND THE IMPORTANCE OF THE ZENITHAL SUN

Not only has a written historical record survived, but the people, their habits, and their customs have also persisted. Thus, a study of the contemporary ethnographic record pertaining to astronomical observations may be as important to our understanding of ancient astronomy as an examination of the codices and chronicles. This is the astronomy of the people. Here the body of material suggests that many native people still observe the heavens and that solstices, equinoxes, and, especially, solar zenith passages are significant for them. When discussing astronomical alignments in the architecture in Chapter V, we will pay particular attention to these events.

The passage of the sun across the zenith in the tropics and its connection with the 260-day calendar will be discussed in some detail in Chapter IV; we refer to the phenomenon only in an ethnographic context at this point. According to Girard (1948), many zenith solar observatories are still used by the Chorti Maya today, for example, at Tan Sha, Esquipulas, and Chiquimula near the Honduran border and at Nebaj in the Guatemala highlands. The days of zenith passage are marked by observing where the sun rises or sets relative to a prominent feature in the landscape. The Hopi of Arizona employ a similar technique. The nineteenth-century traveler Alexander Stephen (see Parsons, 1936) has supplied us with a map of the horizon showing the important sun positions marked by images of the solar disk (Fig. 13). Among the Chorti, the rise-set directions of the sun on the days of zenith passage are actually regarded as east and west, replacing two of the conventional cardinal points, which lie several degrees to the south.

In southern Mesoamerica, these zenith passages serve a practical purpose. The first one announces the rains at the end of April telling that it is time to clear the fields for a planting, and the second, about August 12 or 13 in Guatemala, also signals rain accompanied by wind. These events are attended by elaborate ritual. In the village of Chi-

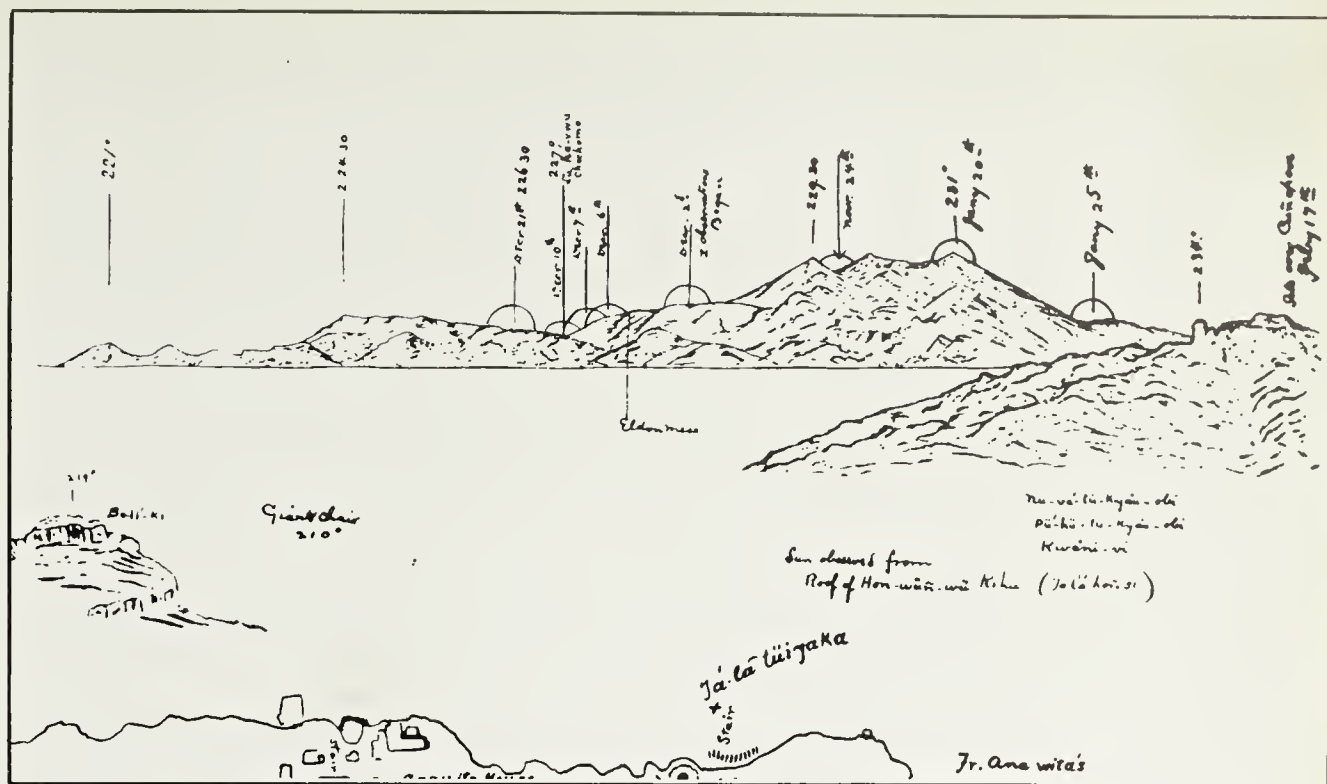


FIG. 13. Hopi observations of the sun at the horizon. The technique of using prominent features of the landscape to delineate a celestial solar calendar was common in ancient America and in some places survives to the present. (Parsons, 1936, 2:map 4; reprinted courtesy of AMS Press, New York)

quimula a parade proceeds from the house of the Virgin to the house of Santiago. The zenith passage dates are announced by the relative position of Orion's Belt, the Pleiades, and the Southern Cross in the night sky. In the evening twilight on the day of the first solar zenith passage in modern Guatemala, the Pleiades can be seen heliacally setting, while the Southern Cross begins to rise low in the southeast. Orion's Belt disappears in the west about two hours later. At sunset on August 12, the Southern Cross undergoes heliacal setting while at sunrise on that date the Pleiades can be found transiting the zenith (Girard, 1948).

Nuttall, in a number of early twentieth-century works (1901, 1906, 1928), refers to the widespread practice of the observation of two zenith passage dates in the calendar. She suggests that the appropriate times were marked by priests watching the noontime shadow of a gnomon, or vertical stick, planted in the ground. At the shadowless moment (high noon on the zenith passage day), the solar deity, symbolized by the Diving God so prominent on the sculptured friezes of many Mesoamerican buildings, would descend to earth portending the torrential rains that were sure to follow. Sometimes these gnomons took the form of stelae, thrones, altars, or even towers.

Believing it to be an integral part of the true Mexican heritage, Nuttall attempted to resurrect the old native practice of marking the zenith passage. In an unusual paper written in 1928, she proposed that all the elementary schools of Mexico should enact the ancient ritual on

the appropriate days. Accompanying a table listing zenith passage dates in the larger villages were these special instructions to the teachers:

- I. Read this pamphlet before carrying out the ceremony, emphasizing to the students that the symbolism of the act is the gratitude of the earth to the sun, to whom she offers her flowers, fruits and seeds in an action of thanksgiving for having produced them; and also that the sun's zenith passage is an omen of copious rains which will fertilize the earth.
- II. Tell the children to attend dressed in white and with a crown of flowers on their heads.
- III. Instruct the children to bring baskets with flowers.
- IV. Place a post in a vertical position which must be perfectly confirmed as such.
- V. On the 17th of May, 15 minutes before 12:33 in Mexico City (or if the ceremony is to be carried out in some towns of different states, the teachers should see the accompanying list at the end of the pamphlet) bring the children to the place in which the post is located and initiate some dances that the teachers of physical education will have taught them previously.
- VI. At the solemn moment the children must throw the flowers that they carry in the baskets and sing songs referring to that act.
- VII. If it is possible, at the apex of the post place a bunch of ribbons which will be distributed among the children who, while executing the dance will wrap them around (the pole) until they can no longer do so; then they will undo the ribbons until they are again placed in their original state. This dance, called the Dance of the Ribbons, was executed by the native indians in such a way and can still be seen on religious days celebrated in San Juan Teotihuacan.
- VIII. It is recommended that the teachers use this occasion as a guide of great interest in order to carry out some studies of historic, geographic or cosmographic character related to the act.
- IX. Teachers are begged to read this pamphlet with the greatest of care and, during the ceremony, to develop according to their judgment those ideas which seem to them will make the solemn occasion its greatest success. (Pp. 3-4)

Evidently, rituals connected with the solar zenith passages enjoyed widespread use—a decree issued by King Philip II of Spain in 1577 states that in order to facilitate good government in the Indies the authorities of every city and town must give exact reports of their latitude and the dates of the sun's zenith passage. Knowing these dates, the Spanish civil and religious authorities would be able to foresee the occurrence of any demonstration linked to the ancient solar cult.

Appearing in the appendix to J. L. Stephens' *Incidents of Travel in Yucatan* (1843) is a document on the ancient chronology of Yucatán by

Don Juan Pío Pérez, a political chief of Yucatán at the time of Stephens' visit. The vague year and the 260-day cycle, both basic calendar units in ancient Mesoamerica, are among the recognizable elements derived from preconquest days. On the origin of the calendar, Don Juan refers specifically to solar zenith passage:

To this day the Indians call this year Jaab or Haab, and, while heathens, they commenced it on the 16th of July. It is worthy of notice that their progenitors, having sought to make it begin from the precise day on which the sun returns to the zenith of this peninsula on his way to the southern regions, but being destitute of instruments for their astronomical observations, and guided only by the naked eye, erred only forty-eight hours in advance. That small difference proves that they endeavored to determine with the utmost attainable correctness, the day on which the luminary passed the most culminating point of our sphere, and that they were not ignorant of the use of the gnomon in the most tempestuous days of the rainy season. (1:280)

One need not employ the shadow cast by a gnomon to observe the zenith passage. At Xochicalco, an archaeological site in Morelos state, Mexico, we find a number of subterranean galleries partially hollowed out by human hands. In two of them, vertical shafts extend from the cave to the surface of the ground above. An observer situated beneath one of these openings 12 meters below ground level can see a small circular patch of blue sky overhead. On the occasions when the sun passes the overhead point, it throws a powerful ray of light into the darkened environment. Though these shafts have been called chimneys or ventilators by some investigators, they may have served as zenith solar observatories. A similar example of a zenith sight tube, in this case totally man-made, occurs in Building P, one of the principal edifices fronting the east side of the open plaza at Monte Albán, Oaxaca, Mexico (see Fig. 85). The placement of this building turns out to be astronomically related to other buildings at the site, as we also shall see in Chapter V.

The Ixil people of remote northwest Guatemala were still using a 260-day calendar in the 1940's when ethnologist J. S. Lincoln (1942) visited there. One shaman kept the count of 13 numbers while another specialized in the 20 day names; among these days the natives tallied Imux (Imix), I'q (Ik), and Akbal in order just as their ancestors had done before the conquest. The immutable 260-day cycle² was correlated with the 365-day year, and even year bearers (day names assigned to the start of the year) were designated along with attendant ceremonies. This remarkable twentieth-century survival is testimony to the tenacious conservatism of the Maya people.

A modern ethnographic record of the old Maya solar year (Haab) was recently discovered in Milpoleta, a remote Chamula Indian village in the Mexican state of Chiapas, where a calendar board (Fig. 14) made from an old door panel was found by anthropologist Gary Gossen (1974b). It had been inscribed by a local shaman with a series of charcoal marks corresponding to the days of the vague year. The tally

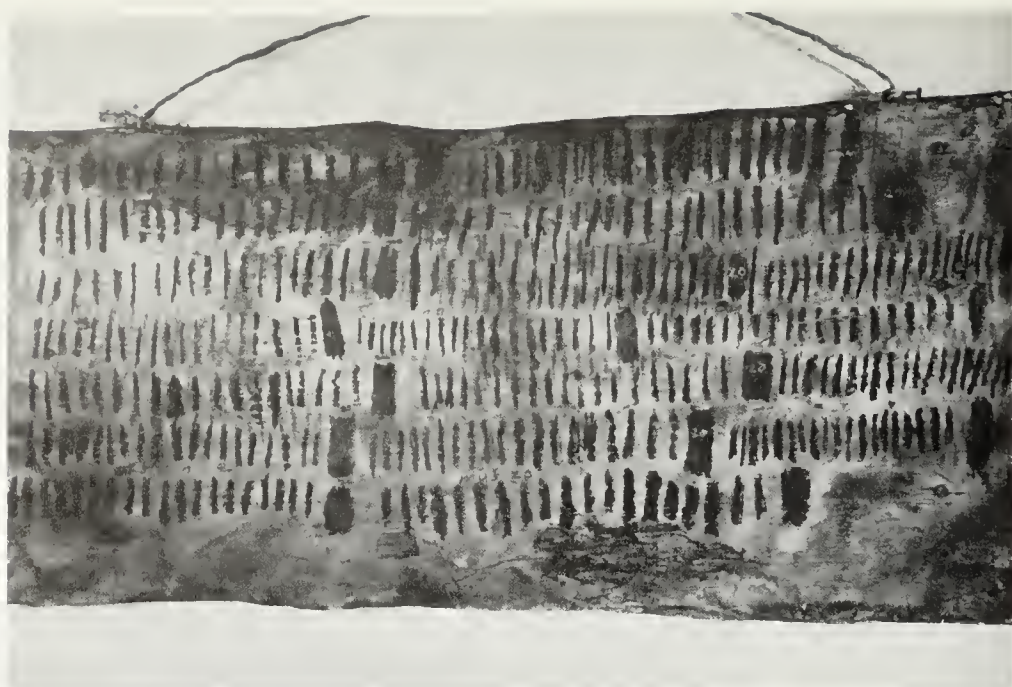


FIG. 14. The calendar board of Chamula. Every twentieth day records a heavy mark to stress completeness of a cycle, which, as we shall see in Chapter IV, was an ancient Maya temporal concern. (Marshack, 1974, p. 256; courtesy of Gerald Duckworth & Co. Ltd.)

marks can be read from left to right beginning at the top. Note that the twentieth mark in each series is heavier than the others. Altogether eighteen series of twenty marks and a single grouping of five marks fill the board—365 days in all. The unlucky 5-day month called C'ayk'in (instead of Uayeb as it was named by the Maya) appears at the middle of the second line for the particular vague year recorded. When Alexander Marshack (1974) of the Peabody Museum studied the board using infrared photography, he found that it had been erased and reused for over a century by the shaman's ancestors.

Further studies of the Chamula board and its users have revealed that these people, like their predecessors, are very interested in time-keeping. The sun appears to be the principal deity and the old solar calendar still functions for the purpose of regulating agricultural activity. It is also used to determine dates of civic and social significance as well as religious festivals.

Ethnologists J. A. Remington (1977) and G. Urton (1978a) are among the new breed of interdisciplinary scholars with a sound knowledge of positional astronomy. They have devoted considerable time to the study of current astronomical practices among Native American people. Residing in the highlands of Guatemala, Remington interviewed Quiché and Cakchiquel informants about their cosmological and astronomical beliefs. As the historical record predicted, she found a strong bond between the calendar and divination. The connection was particularly significant for the 260-day cycle, which is still utilized. Among the astronomical phenomena feared most were the prophetic eclipses. These seem to have been regarded almost exactly as Sahagún relates in Book 7 of the Florentine Codex. Venus is the most

important planet and certain constellations and stars (the Pleiades, the Hyades in Taurus, Castor and Pollux in Gemini, Regulus, Scorpio) are regarded with special importance because of the times they undergo heliacal rise or set.

On matters of astrology, time, calendar, and asterisms, the informants gave their interrogator few surprises, but when questioned, the Cakchiquel informants revealed the use of a curious non-Western orientation scheme. They say that the sun and the moon always follow separate paths and that each path changes with the season. The sun rises to the north when the nights are short (rainy season). Here there is some confusion since sketches accompanying their description imply that the sun always rises in the southeast but more to the north in the rainy season (March 22–September 22) than in the dry season (September 22–March 22). Three classes of stellar paths are recognized: (a) short arcs concentric about the Pole Star which describe the motion of the circumpolar stars (Ursa Major = “the car with a tail”: belongs to this category); (b) short arcs to the south, including the Southern Cross; and (c) star paths which pass overhead—they make half circles on the sky and are often crossed by the course of the sun and moon. Orion is a member of this latter group.

In his orientation scheme, the Cakchiquel shaman clearly seems to be distinguishing among the celestial equator, the ecliptic, and the lunar orbit. He utilizes the celestial paths not only to keep the time of year but also to mark the time of day and night. When Remington queried an informant about where a star visible in the sky earlier in the year could be found *now*, the respondent replied by pointing downward at a 30° angle under the horizon to the east. He then pointed upward to where it would have been located at sunset. The response was corroborated by similar replies given in separate interviews by other medicine men. But as the ethnographer might fear, even the native population of the remote Guatemala highlands cannot escape Westernization. One day while interviewing a Quiché priest, Remington asked about a UFO sighting which had been reported there a few years ago. The shaman casually stated that it was probably an experimental aircraft of the Russians or the Americans. When the anthropologist suggested that the supposed technology seemed more advanced than that, the shaman, seeming indignant at the questioner's lack of faith in technology, proposed that any civilization able to land a man on the moon could surely develop such an advanced aircraft.

Urton's studies have concentrated on the astronomical habits and customs of the people of the remote Andean villages near Cuzco, the ancient Inca capital. He finds that in many cases they connect the orientation and arrangement of their villages directly with events in the heavens, particularly those near the horizon. They seem to be especially aware of the positions at which the sun rises and sets on the days it transits the zenith and the nadir. The sensitivity to horizon bearings may be a remnant of concepts employed in the design of the lineations on the Nazca Desert or the *ceque* system of Cuzco. Many of the modern Andean constellation patterns, no doubt derived from ancient ancestry, make use of dark areas of the southern Milky Way to form unique black constellations possessing animal forms (see Fig. 15).

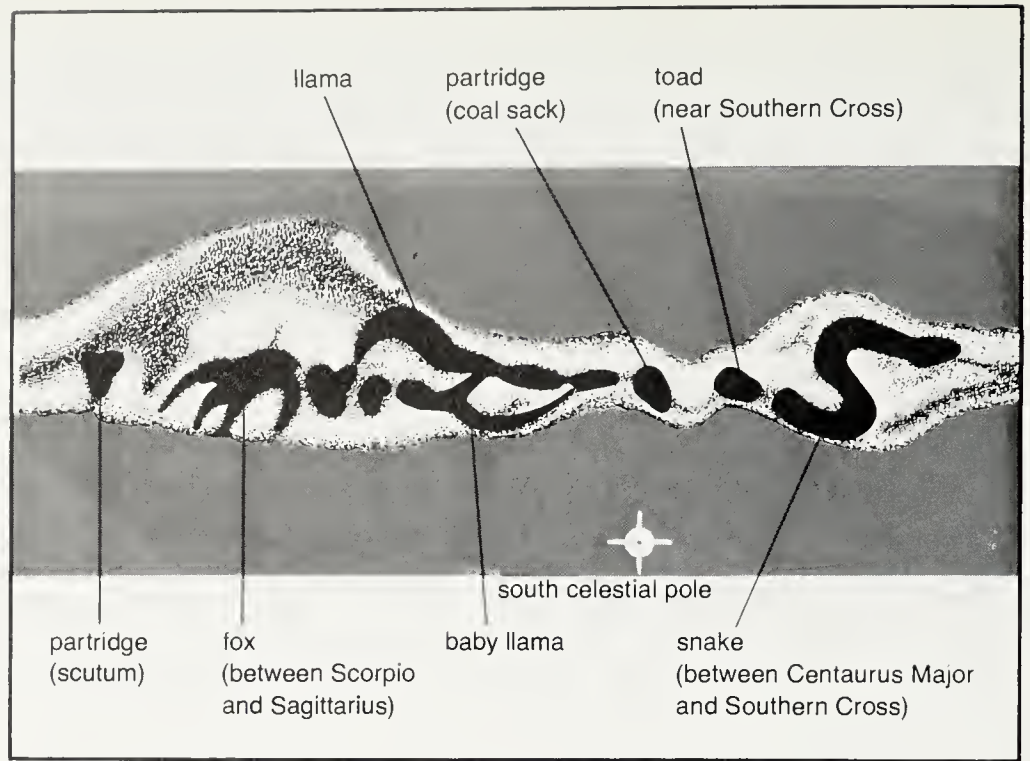


FIG. 15. Black constellations. (Diagram by P. Dunham; I am indebted to Gary Urton, 1979, for permission to adapt this figure)

These descriptive examples from cultural anthropology past and present reveal that we are separated from the ancient American mind by many centuries. We find ourselves further disadvantaged by the availability of but a small portion of the historical legacy which we view only after it has been filtered through Spanish eyes. Our Western cultural chauvanism, so difficult to suppress, often makes the picture even more hazy. In spite of these handicaps, we have seen that a rich historical and ethnographic base relating to ancient Mesoamerican astronomy awaits our considered interpretation. After acquiring the basic astronomical tools, it shall be our goal in the remaining chapters to examine the two most concrete cultural components to generate astronomical output in ancient America: the written calendars and the landscape and its architecture. The concepts gleaned from studies in each of these fields must be integrated with the work of the ethnohistorian and anthropologist who continue to provide us with the kind of knowledge reviewed in this chapter. Only then can we hope to learn the truth about the breadth and depth of ancient New World astronomy.

ADDITIONAL READINGS

The following general references on the civilizations of ancient Mesoamerica provide excellent background for the study of Mesoamerican archaeoastronomy:

- Coe, M. D. 1962. *Mexico*. New York: Praeger.
- . 1966. *The Maya*. New York: Praeger.
- Morley, S. G., and G. Brainerd. 1946. *The ancient Maya*. Stanford, Cal.: Stanford University Press.
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- Sanders, W., and B. Price. 1968. *Mesoamerica: The evolution of a civilization*. New York: Random House.

III. Astronomy with the Naked Eye

“... in studying the convoluted orbits of the stars my feet do not touch the earth, and, seated at the table of Zeus himself, I am nurtured with celestial ambrosia.”

—Ptolemy (1898, preface)

THE CELESTIAL SPHERE: COORDINATE REFERENCE FRAMES

In order to understand what ancient people thought about their universe, we must try to witness its contents and events through their eyes, unencumbered by the technological devices of modern times which, though they vastly extend our vision, also alter our interpretation of the natural world.

In this chapter we attempt to assemble and discuss most of the obvious celestial events that ancient astronomers would have viewed with the naked eye. The reader will find the material treated in this chapter most useful in connection with specific discussions in the other chapters; therefore, the presentation should be regarded as encyclopedic rather than prose. Special “boxes” concentrate on the simplest appearances alone, while the body of the chapter attempts to show how the observer, using only naked-eye observations, can predict future celestial courses. Description and recognition rather than scientific explanation of phenomena will be stressed. A compact glossary of terms most often employed by positional astronomers accompanies this chapter (Appendix A). The reader may find it helpful to consult the glossary especially while reading this first section. Thus, the technical jargon that often accompanies the scientific textbook approach is isolated and minimized.

Whether ancient or modern, all phenomena in the heavens appear to take place on the inner surface of a huge screen having roughly the shape of a hemisphere. We can think of the *celestial sphere* as a sphere of arbitrary extent centered about an observer located at some position on earth. The situation as we would imagine it is pictured in Fig. 16, with the size of the sphere vastly shrunk to fit the page. The dashed part of the three-dimensional diagram lies behind the page while the solid part protrudes from the page. Now we view the position of a star, R, on the celestial sphere and wish to identify its location in the heavens.

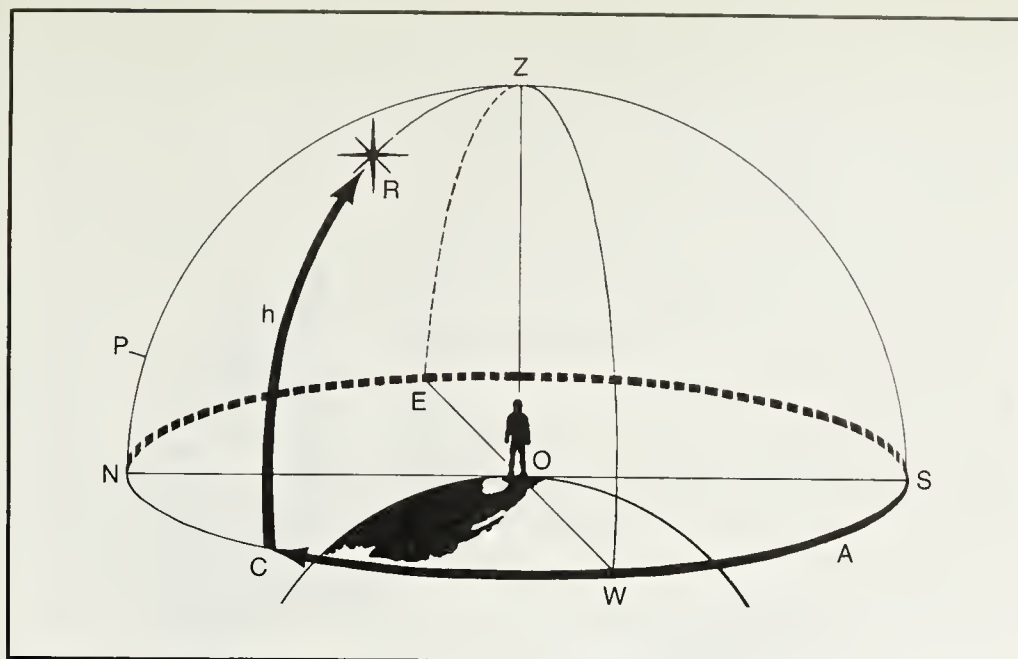


FIG. 16. The sky (celestial sphere) as it appears to us in its simplest form. The observer is at O on the surface of the earth. (Diagram by P. Dunham)

In Western astronomy we do so by specifying its two coordinates in a system which utilizes the horizon NESW as a fundamental reference circle, the zenith (Z) functioning as its principal pole. We call this the *horizon reference system*.

We identify the *azimuth* of the star with its position along the horizon measured toward one's right when facing north, while the *altitude* gives the angular distance of the star measured vertically upward from the horizon along the segment CRZ, which is called the vertical circle of the star.

In Fig. 16 the azimuth of R is approximately 330° ; the altitude is about 60° . Both coordinates are indicated by heavy black arrows. The situation examined on a larger scale is rather like that depicted in Fig. 18. The observer is still at O and the star at R but the earth is drastically shrunk. The poles of the rotating earth are extended to the sky at P and P'. The stars move and all short-term motion in the heavens pivots about these poles. We may take this picture back to the local scene of Fig. 16 and mark the position of the celestial pole on the sky by P, a place closely attended today by Polaris, the Pole Star, brightest star in the Little Dipper of the astronomy of the Classical World. The true north or cardinal north direction,¹ used to define azimuth, is then given by dropping the arc PN perpendicular to the horizon.

The azimuth of the north celestial pole, P, is 0° ; the altitude of the pole, the length of the arc NP in degrees, is about 20° . For those who care to follow the simple proof described in Fig. 17, it can be shown quite easily that the altitude of the celestial pole is equivalent to the observer's latitude,² a relation which will be useful to us when we begin to consider how the constellations are arranged in the sky as viewed from different latitudes.

Now, as we already stated, the position on the celestial sphere of

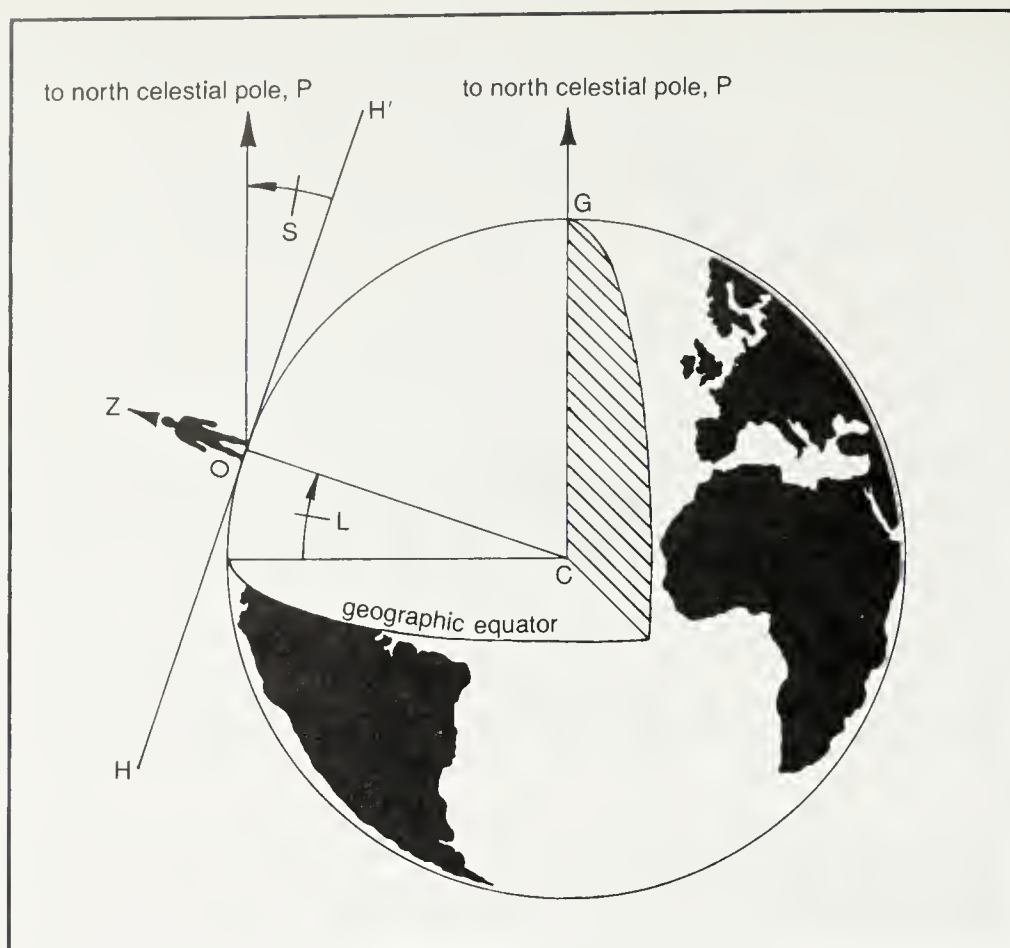


FIG. 17. The altitude (angle S) of the north celestial pole equals the latitude of the observer (angle L). The observer stands at O , and C is the center of the earth. (Diagram by P. Dunham)

the north celestial pole is closely marked by Polaris, the Pole Star. If we stand at the geographic pole, the Pole Star will lie at the zenith (altitude = latitude = 90°). Imagine that we begin a journey from the north geographic pole to the equator, watching the Pole Star as we go. As we progress southward, Polaris will fall lower and lower in the northern sky. At New York (42° N latitude) the altitude of the Pole Star will be 42° , or nearly halfway to the zenith. At Miami (latitude 26° N) we will see Polaris at an altitude of 26° above the north point of the horizon. Finally, when we arrive at the earth's equator (latitude 0°), Polaris will coincide with the north point of the horizon exactly. Fig. 20 helps illustrate this principle by showing the celestial scenery at different geographic latitudes.

While the horizon system can be used to specify the location of a celestial body in the sky at a given time, we note that azimuth and altitude are constant neither with time nor with the location of the observer. Because the earth rotates on its axis, we see the stars move across the celestial sphere circling daily around Polaris, which remains nearly fixed. Thus, the azimuth and altitude of any star change continually. See Box A for a direct manifestation of this simple motion. Also, as observers move over the surface of the earth, they carry with



Box A

them their own zenith and horizon; consequently, an azimuth and altitude pair describing the location of an object at 8 P.M. in the sky over Miami differs from that observed at 8 P.M. in New York for the same object.

In order to describe the changing aspect of the heavens, we will employ a second reference system devised by Western astronomers, a reference frame which moves with the stars as the earth rotates. These new coordinates, called the *equatorial system of coordinates*, are derived by reflecting the earth's geographic coordinates upon the celestial sphere, as in Fig. 18. The celestial equator XWBE becomes the celestial counterpart of the geographic equator just as the celestial poles PP' serve as a reflection of the geographic poles. In other words, in the moving reference system, the celestial equator is like the horizon and the celestial poles are like the zenith and nadir. Because the earth rotates on its axis from west to east (the direction indicated by the small arrow enveloping the earth), the observer sees the stars move in the opposite direction across the sky from east to west (the bold black arrow shows about 2 hours' worth of this turning motion). Thus, while the celestial sphere turns by an amount indicated by the bold arrow, R shifts its position along a curved arc to T.

To describe the position of star R in the equatorial system, we choose the vernal equinox (V) as a fixed point on the celestial sphere. It represents one of the points where the ecliptic, or apparent annual path of the sun on the celestial sphere, crosses the celestial equator. Because the vernal equinox moves with the stars as the heavens turn, the coordinates appended to it will not change.³

Accordingly, we may define the *right ascension* (α) and *declination* (δ) coordinates of the star R in the equatorial system. In Fig. 18 the approximate equatorial coordinates of R (designated by heavy lines) are α (right ascension) = 30° or two hours and δ (declination) = $+60^\circ$.

A third reference system, the *ecliptic system of coordinates*, is convenient for tabulating the movement of the planets that travel close to the ecliptic. The fundamental reference circle is the ecliptic

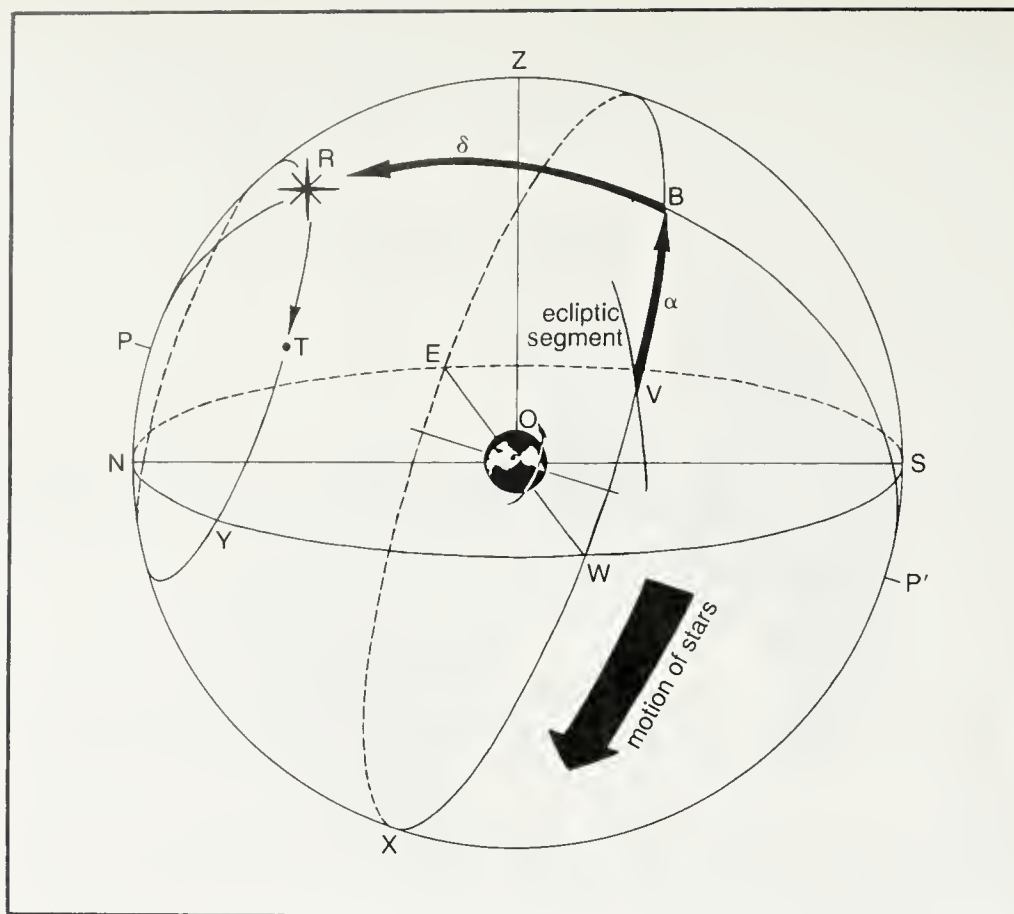


FIG. 18. Right ascension (α) and declination (δ), celestial coordinates in the equatorial system. The earth is at the center of the celestial sphere, which has been shrunk from its apparently infinite size. (Diagram by P. Dunham)

and its poles are the poles of the ecliptic. The coordinates are named celestial latitude and longitude. They are defined like right ascension and declination, except that the ecliptic replaces the celestial equator.

We have seen that if we continue to view our star *R* through the night it will move along an arc parallel to the equator, ultimately arriving at position *T*. *R*'s coordinates in the horizon system will have changed. Its azimuth will have increased and its altitude decreased, but its equatorial coordinates still will remain the same. Finally, starset would occur at position *Y* where the star trail *RTY* intersects the horizon.⁴ Recalling that the altitude of the celestial pole *NP* is indicative of the observer's latitude, we see that the angle *TYW*, which the star trail makes with the observer's horizon, depends upon the latter's latitude. Compare the angles that the star trails make with the horizon at various latitudes in Fig. 20. If the observer is close to the geographic equator, *TYW* must be nearly 90°. For an observer at latitude zero, the stars will plunge vertically into the horizon. Conversely, observers in the Arctic and Antarctic regions will see stars rise and set at grazing incidence to the horizon. For an observer at the north geographic pole, star trails will be exactly parallel to the horizon and stars will neither rise nor set. Such a remarkable contrast in the aspect of the heavens might be expected to produce very different cosmic outlooks for tropical astronomers as opposed to skywatchers in the temperate latitudes.

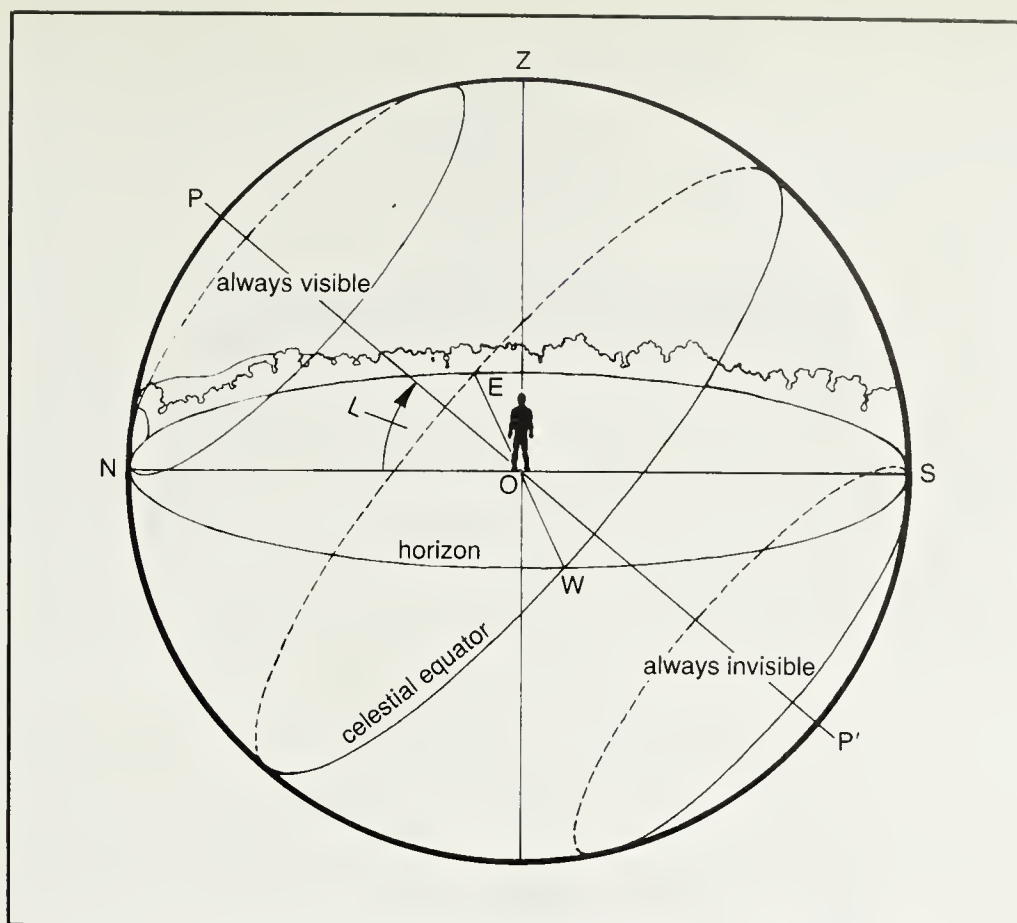
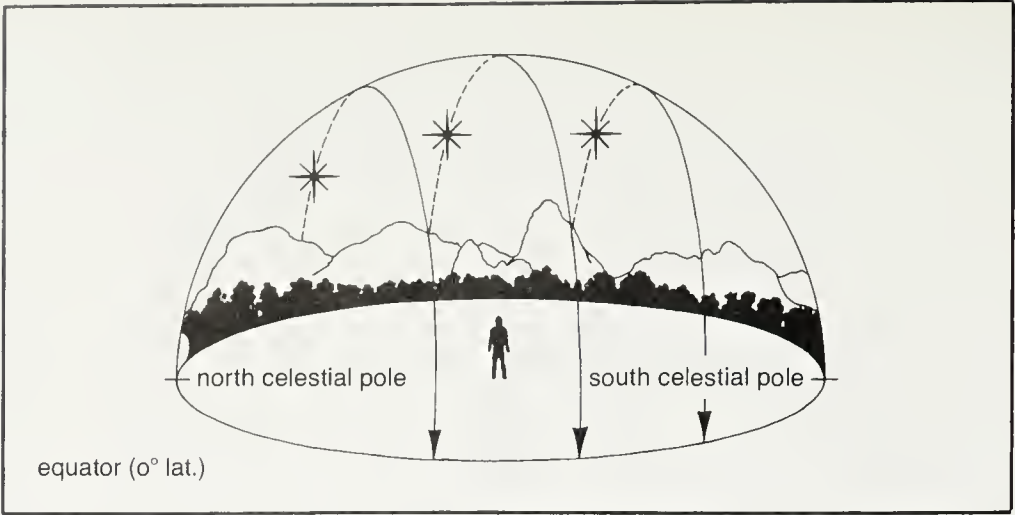


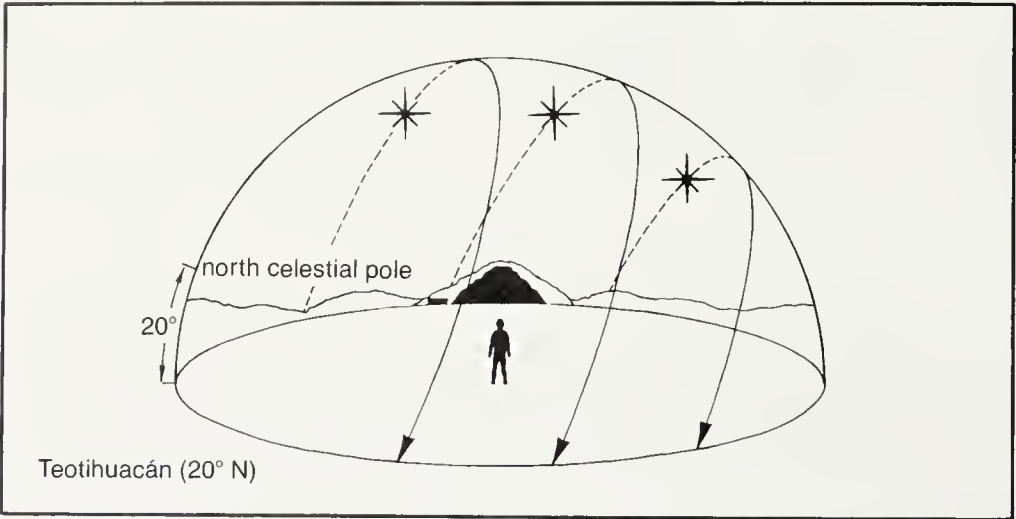
FIG. 19. Three star zones on the celestial sphere. For a northern hemisphere observer, those visible above the horizon every night (*left cap, north*), those never visible (*right cap, south*), and those in a wide band between the two caps which are sometimes visible and at other times invisible. The latter zone diminishes while the caps increase as we consider observers farther away from the earth's equator, where angle L becomes larger. (Diagram by P. Dunham)

We also learn from an examination of Figs. 17 and 18 that (*a*) not all stars will be visible from a given latitude and (*b*) some stars will always lie above the horizon. These principles are illustrated in Fig. 19. The visible circumpolar cap includes all stars observed at a given latitude which never set. The invisible circumpolar cap contains all stars which never rise. The area of the celestial sphere covered by these caps increases with increasing latitude. At latitude L in the Northern Hemisphere all stars with northern declinations greater than $90^\circ - L$ are perpetually visible. By similar reasoning, all stars with southern declinations greater than $90^\circ - L$ are perpetually invisible.

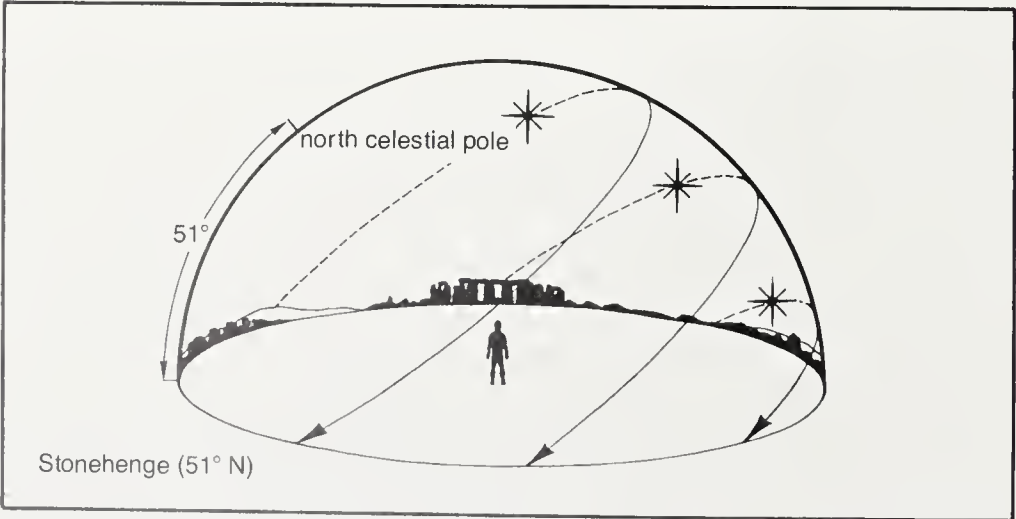
Since we know that the greater the latitude the higher the celestial pole will be in the sky, we can see, by comparing Figs. 19 and 20, that latitude differences render contrasting views of the celestial sphere. In high northern latitudes where all heavenly motion appears to be pole-centered, we see fewer stars than at the tropics, and most of them are perpetually visible. Among the native people of North America, circumpolar constellations, such as the two Dippers and Cassiopeia, are closely watched, often being employed as timekeeping devices (see Fig. 22*a*, the north circumpolar chart). A civilization in the tropics might



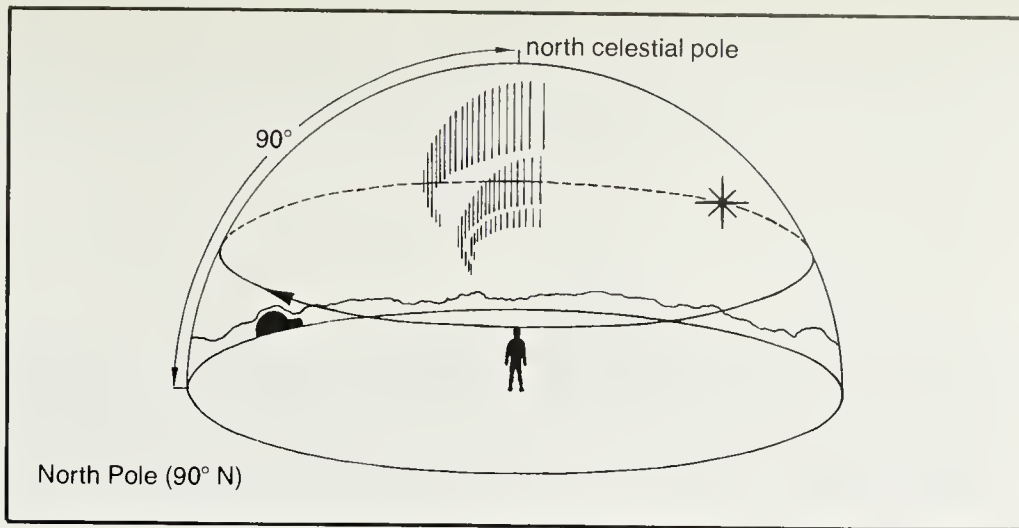
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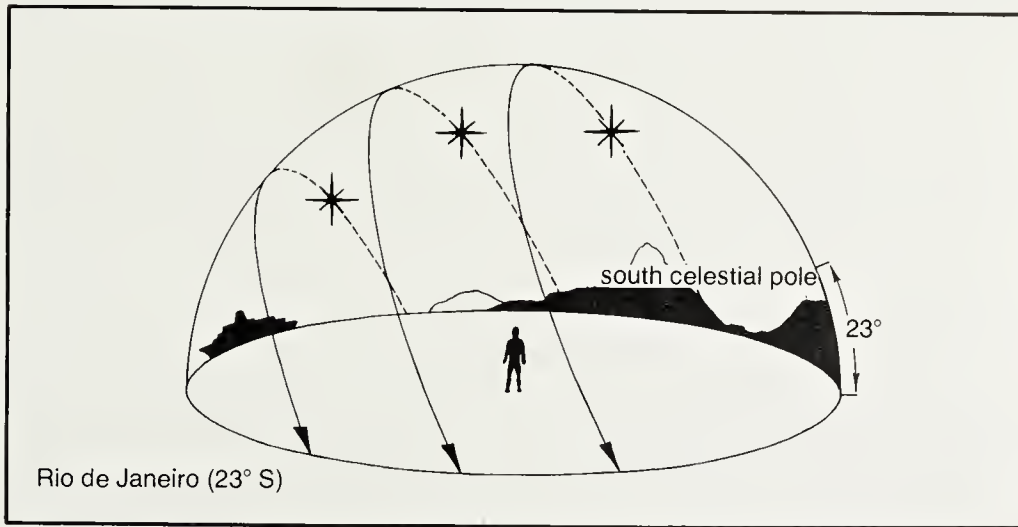
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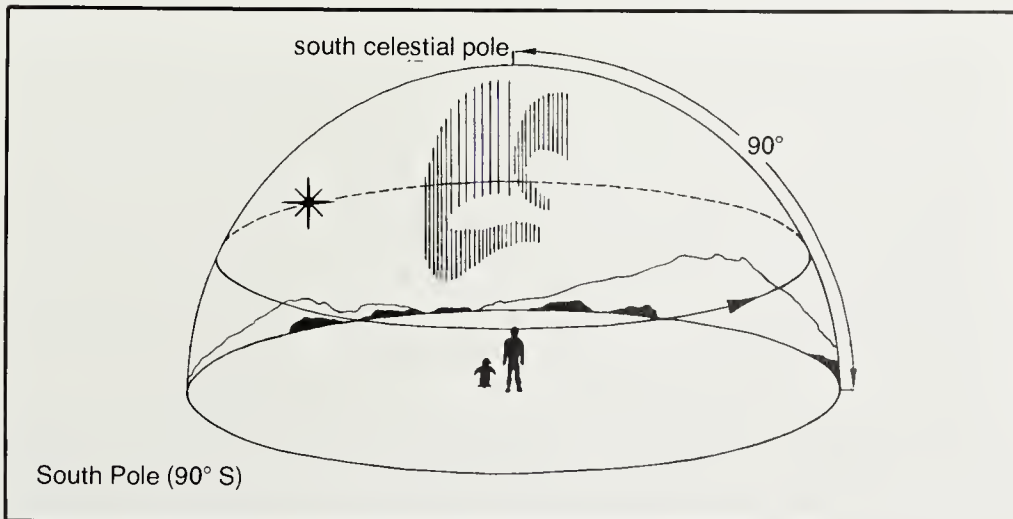
c



d



e



f

FIG. 20. As these scenes depict, the stars appear to take very different paths for observers at different latitudes, and the position of the fixed Pole Star (marked "north celestial pole" in the northern hemisphere) on the sky also changes. Its altitude is the same as the latitude of the observer (see also FIG. 17). (Diagrams by P. Dunham)

be expected to develop quite a different system of positional astronomy. The people of Oceania created linear constellations, the member stars of which rose and set in vertical tracks over the ocean horizon at approximately the same azimuth. Such a system had considerable utility among races interested in navigation.

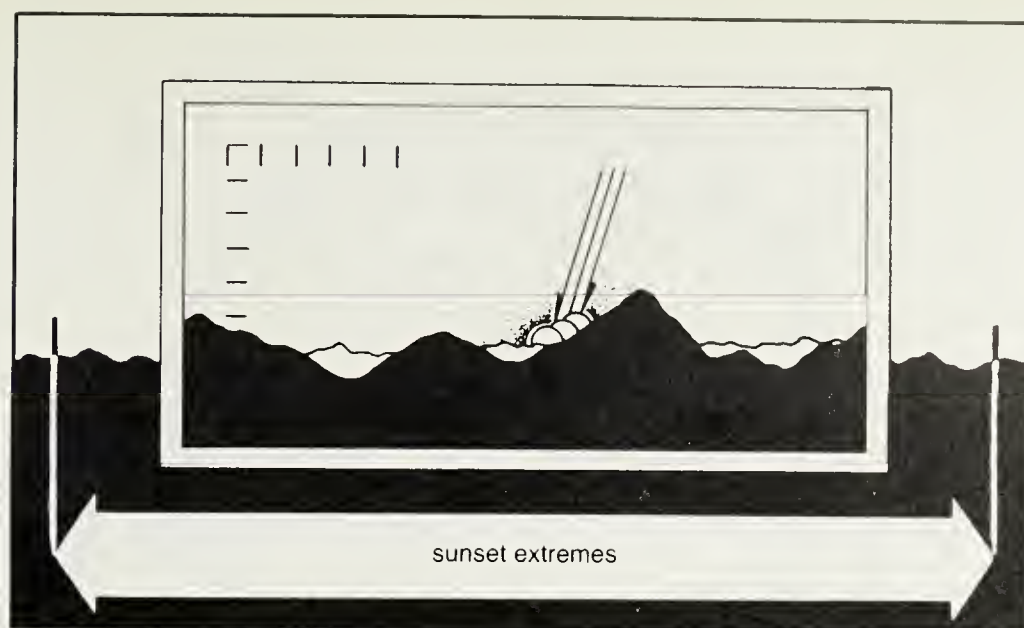
Fig. 20 illustrates why an observer at the earth's equator gets a glimpse of every star in the sky, each rising along a line perpendicular to the horizon. For an equatorial observer (Fig. 20a) the celestial poles rest exactly on the north and south points of the local horizon. At Teotihuacán (Fig. 20b) the stars rise and set at a 20° slant from the perpendicular (a 70° angle from the horizon) as the Pole Star, the pivot of all celestial motion, hangs low in the northern sky 21° above the horizon. For the observer at Stonehenge (51° N latitude) the motion about the pole is even more obvious, as Fig. 20c demonstrates. The Dippers and Polaris are always high in the sky and the sun, moon, and stars graze the trees with their horizontal motion as they rise and set. Perhaps most peculiar of all is the view confronting Arctic observers (Fig. 20d). Situated exactly at the geographic north pole, they see only about half the stars, which always remain in the sky, traveling in diurnal circles of smaller and smaller diameter as the observers cast their eyes toward the zenith. In the southern hemisphere the situation is reversed with the south celestial pole acting as the pivot, as Figs. 20e and 20f show.

CHARTING THE SUN'S MOVEMENT

While the motion of the stars seems quite regular, the sun, moon, and planets demonstrate important exceptions to some of the rules discussed above.

First, let us consider how the sun moves. Like all celestial bodies, it always will rise in the east and set in the west every day. But since the earth revolves about the sun in the plane of the ecliptic once a year in the same direction as it rotates, the sun also will appear to move along the ecliptic from west to east, making a complete circuit of 360° against the stellar background in a tropical year (365.2422 days). *Relative to the stars*, the sun moves about 1° , or twice its own diameter, per day (Box B). Consequently, constellation patterns will appear to shift their positions relative to the sun throughout the year. Because we follow suntime, we will see a given star rise a few minutes earlier each day. Thus, if we view the stars above the eastern horizon opposite the direction of sunset in the darkening twilight on successive nights, new constellations will begin to appear. Those which were visible on the horizon a few weeks earlier will move higher up in the sky.

Fig. 21 provides the reader with a set of simple star maps showing for each month the principal constellations visible in the eastern sky to an observer in low northern latitudes. For higher northern latitudes the southern end of the horizon should be tipped higher, the northern end slightly lower. Each map is intended for use shortly after twilight on the first day of the month for which it is labeled. To use the charts at a later hour on the same night, add one month for every two hours. Thus, the contents of the eastern sky six hours after sunset on July 1



Box B

would be the same as that on October 1 immediately after sunset. Shortly after sunset around the time of the winter solstice (see map for January 1) Orion, recognizable by the bright stars Betelgeuse and Rigel, appears about a quarter of the way to the zenith above the east point, E, as Sirius is about to rise in the southeast. A month later Sirius is well up by sunset and Orion has passed closer to the overhead region by the time it is dark. At sunset on the spring equinox, when Orion and Sirius have already passed the meridian and have begun to descend in the west, Leo, a spring constellation, with its bright star Regulus, has cleared the eastern horizon. In the middle of summer Altair and Vega are the bright stars in the east. At this time, red Betelgeuse and blue Rigel are lost in the sun's glare. These stars return to view in the early morning sky after the sun passes them about mid-July. During June the red star Antares in Scorpio dominates the southeast after sunset; by July, Altair, Vega, and Deneb (just off the chart to the left), the stars of the great "summer triangle," rule north of east. The summer Milky Way stretches in a band low across the eastern sky. By midnight in mid-July (see October chart) the Milky Way has climbed to the meridian (out of the picture) as it stretches from north to south. On successive months following July the Milky Way is seen slightly higher in the sky after sunset, as the maps indicate. Notice also the progress of the ecliptic in the eastern sky as it dances first to the right then to the left of the celestial equator.

In Fig. 22, again we imagine ourselves as northern observers to be inside the celestial sphere and ask what we will view at different times of the year looking first to the north, then to the south.

Looking due north (Fig. 22a): The origin of coordinates is the present position of the north celestial pole. To view the sky at sunset on the first day of a given month use a straightedge for the horizon plane, the right end of the straightedge representing east, the left end west. Hold

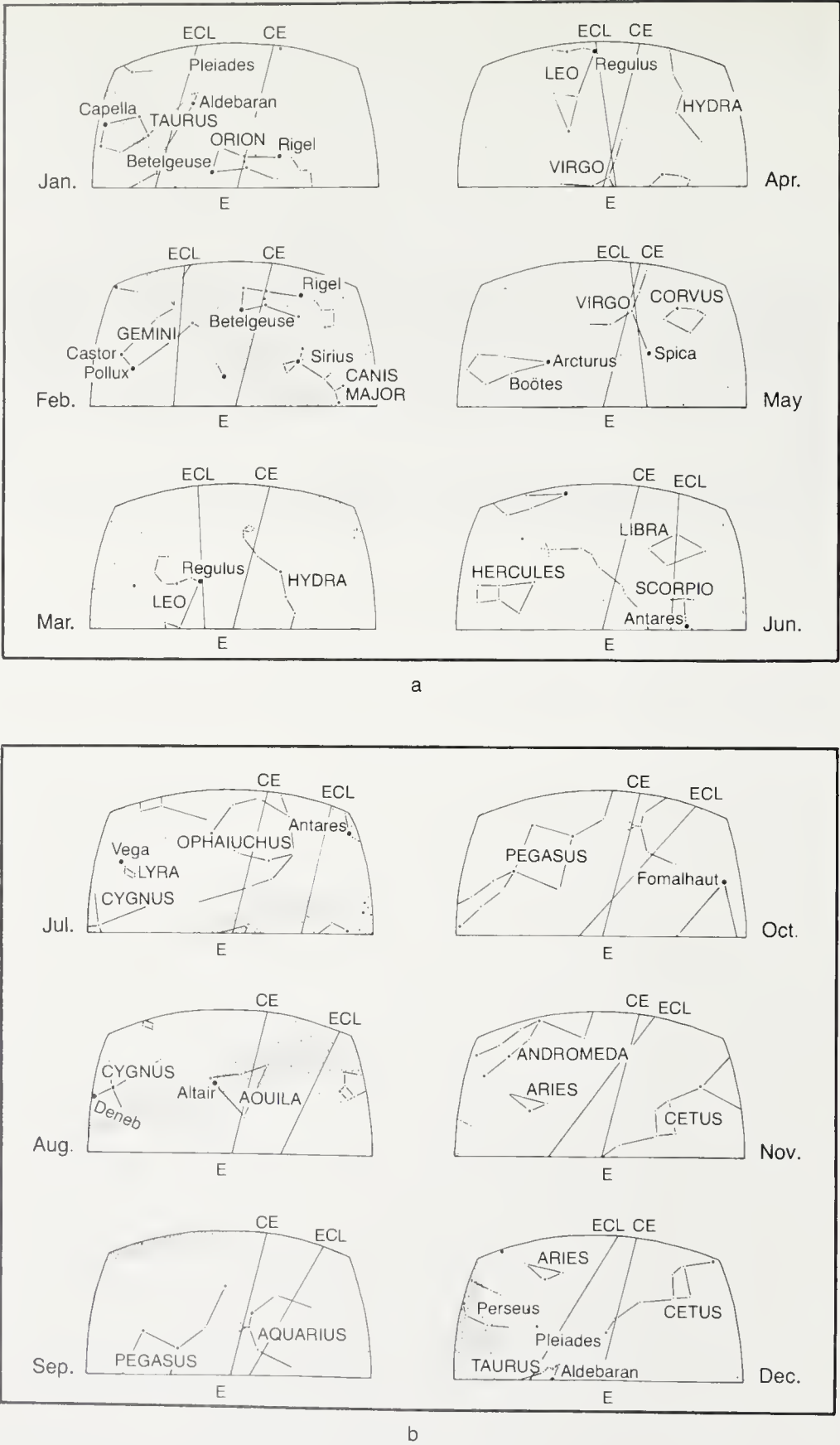
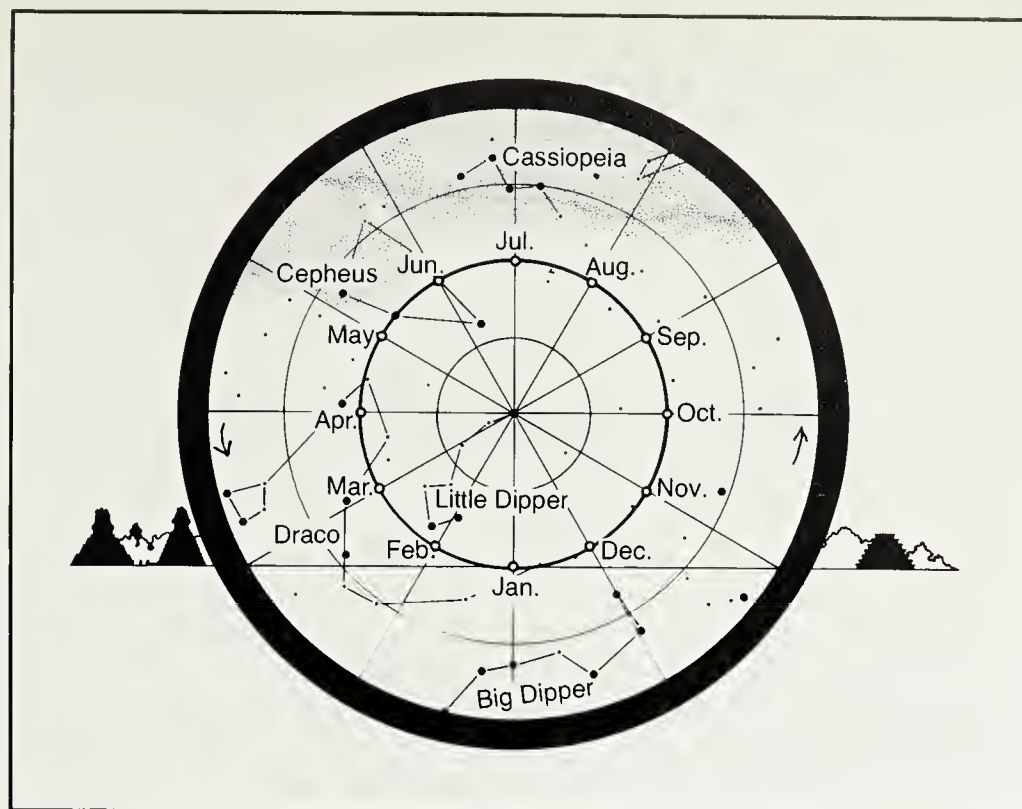
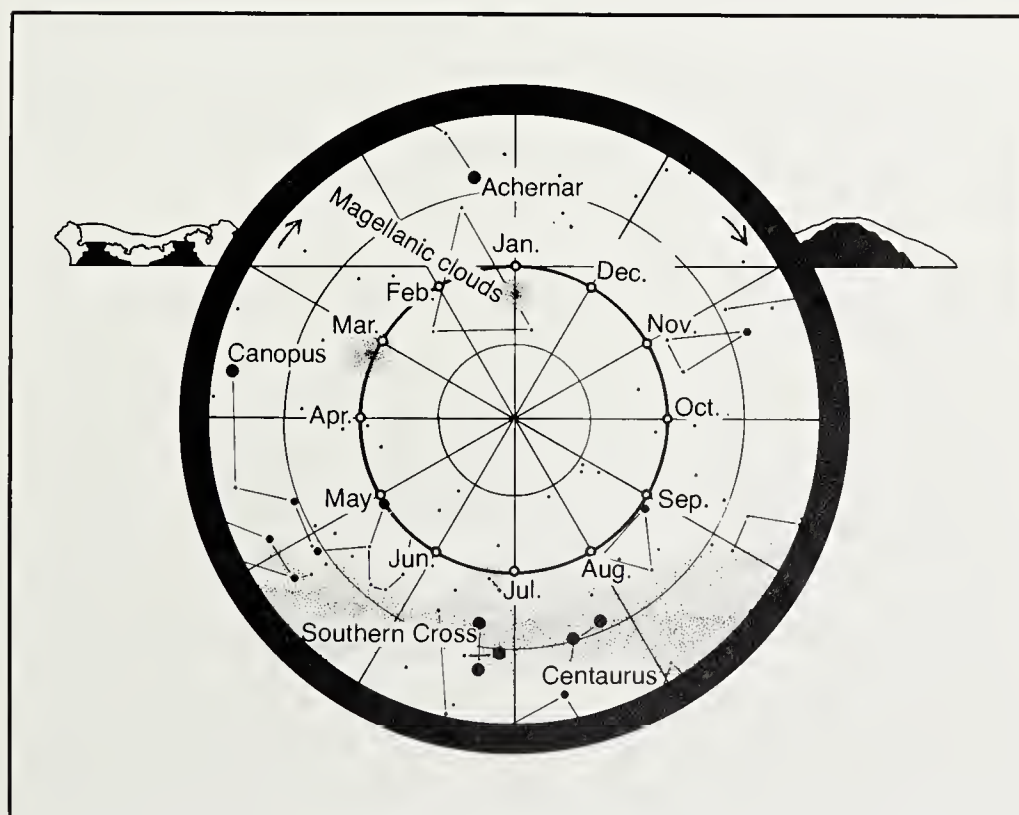


FIG. 21. Year-round views of the eastern sky on the first night of each month at the start of evening twilight. The observer is assumed to be situated in a low northern latitude. For reference, the celestial equator (CE) and the ecliptic (ECL) are drawn in. The Milky Way appears as a dotted zone. (Diagrams by P. Dunham)



a



b

FIG. 22. Nightly views at twilight of the northern and southern circumpolar stars at different times of the year for an observer in 20° N latitude. The horizon for January is sketched in on each diagram. Concentric circles radiate at 10° intervals from the pole. (Diagrams by P. Dunham)

it tangent to the thick circle at the dot marked for the appropriate date. The intersection of the straightedge and the circle represents the observer's north point. Everything lying above the horizon plane on the page will be visible; everything below, invisible. Stars rise in the east (*right*), pass around the pole, always remaining equidistant from it, and set in the west (*left*). Note that stars closer to the pole set at shallower angles relative to the horizon. Exceptions are those lying inside the thick circle. They are perpetually visible on every night of the year (recall Fig. 19) though the orientation of star patterns relative to the horizon is different.

The horizon for January 1 is drawn in for convenience. Cassiopeia and the Milky Way are high above the north horizon, and the stars we recognize as constituting the bowl of the Big Dipper are about to rise.

Looking due south (Fig. 22*b*): The technique for using the diagram is the same. The observer can hold a straightedge tangent to the appropriate dot for a given date on the thick circle by rotating the page. Everything on the side of the straightedge away from the observer will be visible, east being on the left and west on the right. Again the horizon for January 1 is sketched in. Achernar is above the horizon, having risen in the east to the left, but most of the other bright southern stars (the Southern Cross, Alpha and Beta of Centaurus) and the great southern Milky Way lie below the horizon. The zone inside the thick circle represents that region about the pole where stars are perpetually invisible at the latitude indicated. At higher northern latitudes the thick circles in each of these diagrams will expand outward to include stars farther from the poles. In southern latitudes the situation is reversed, with a larger share of the southern circumpolar stars on view while the Dippers and Cassiopeia pass into perpetual invisibility.

We have already stated that the sun rises in the east and sets in the west every day and that it moves along the ecliptic from constellation to constellation in the course of a year.

The combination of the daily and annual motions of the sun in the sky must have confounded the ancients, who surely did not view its compound motion as we do. Fig. 23 should minimize the confusion. Here the observer (O) looks from a low northern latitude at the sun's position (point A) late in the afternoon, say, at four o'clock. The movement of the sun along the ecliptic in one day is given by the arc AB. Note that this motion is contrary to the daily motion of the sun. But, while the sun undergoes this tiny amount of annual motion against the background of distant stars, the rotation of the earth rapidly carries it (and the segment of the ecliptic shown) out of the observer's view below the western horizon along the path labeled "daily motion." Early the next day the sun rises in the east, climbs high in the sky, and then begins to descend once again. Whereas we saw the sun late in the afternoon at point A on the first day, we will see it at point B, very slightly higher and to the north, on the second day. The combined solar motion for two additional days (highly exaggerated) is also shown in the figure. One result of this complex motion is that the rising and setting positions of the sun will change slightly from day to day (see Box B). The

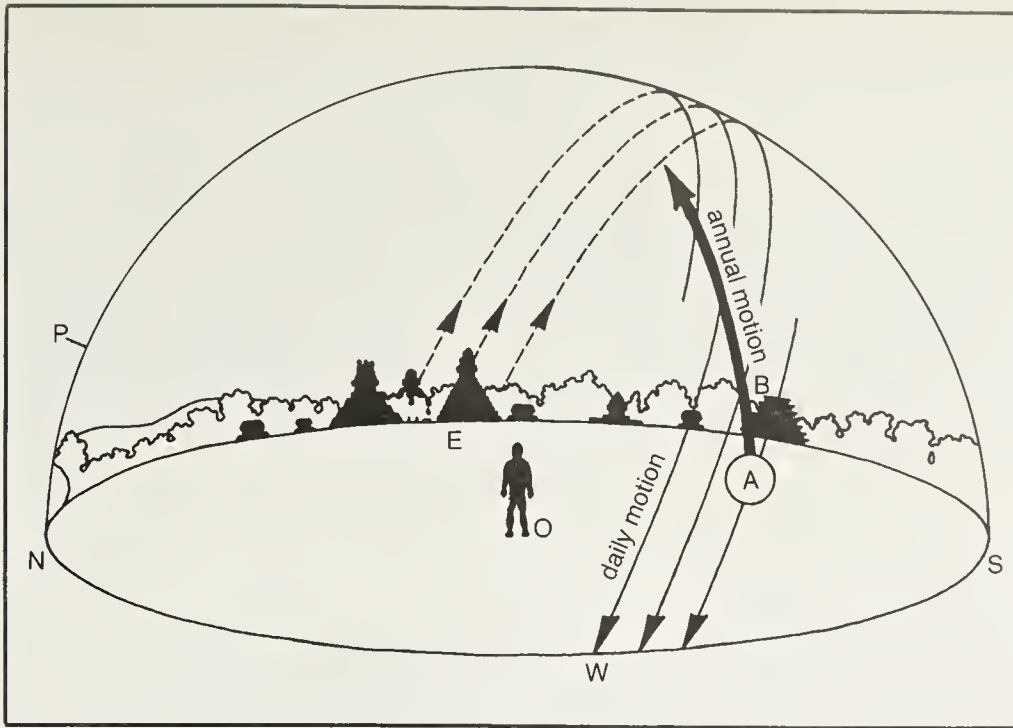


FIG. 23. Daily and annual motions of the sun combined. The sun rises in the east and sets in the west daily, but it also maintains a slow annual track along the ecliptic (*heavy arrow*). As a result, over the year the sun seems to trace out the helical (*corkscrew*) path indicated by the light lines. (Diagram by P. Dunham)

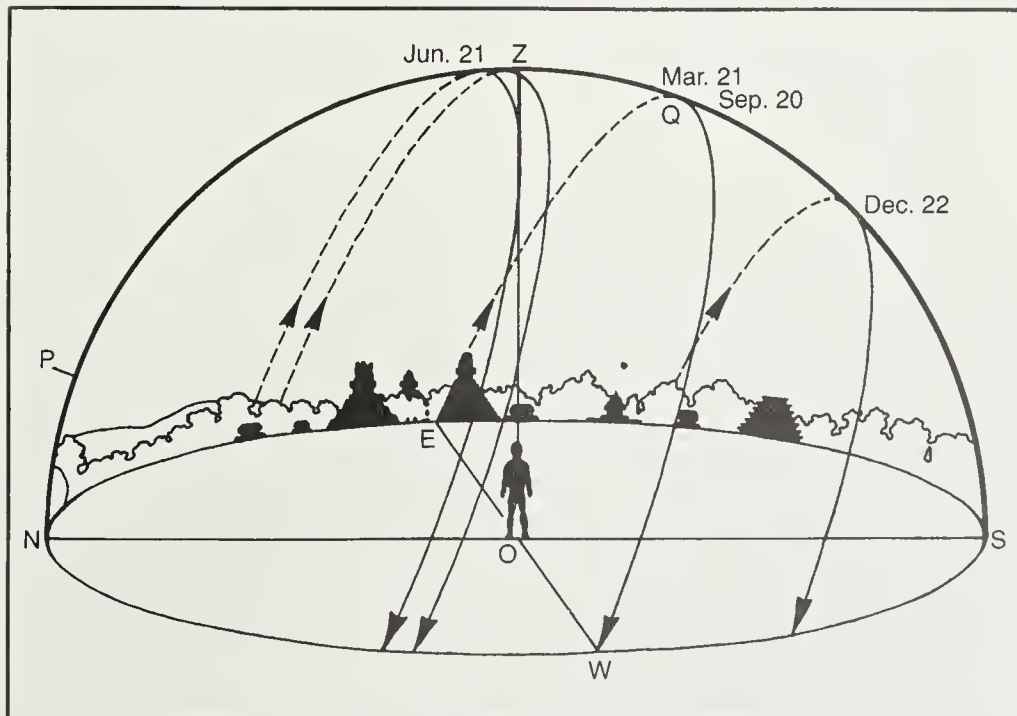


FIG. 24. The daily motion of the sun across the sky is depicted for important days of the year: the summer solstice (June 21 in the northern hemisphere), the winter solstice (December 22 in the northern hemisphere), the equinoxes (March 21 and September 20), and the days of passage through the zenith, Z (dependent upon latitude). Again the observer is in a low northern latitude. (Diagram by P. Dunham)

sun's daily path on selected days of the year is summarized in Fig. 24, which is again intended for an observer in a low northern latitude. On the day the sun arrives at the vernal or autumnal equinox, its *daily motion* across the sky will mimic the celestial equator since it lies precisely on the equator. It will rise exactly at the east point (azimuth = 90°) and it will set at the west point (azimuth = 270°) as shown in the figure. Later in the spring as the sun moves north of the celestial equator and its declination increases, it will rise and set closer to the north point. The sun attains its maximum northerly declination and, consequently, its extreme northerly rising and setting points (approximate azimuth 65° and 295° , respectively) about June 21, the summer solstice. At this time the sun's declination is $+23\frac{1}{2}^\circ$.

At noon on June 21 the sun reaches its greatest altitude. It then begins to move southward again, crossing the equator on September 20, when it rises at azimuth 90° and sets at azimuth 270° . At the winter solstice (about December 22) the sun reaches its greatest southerly declination ($-23\frac{1}{2}^\circ$). At this time it rises and sets at azimuths nearest the south point of the horizon (about 115° and 245°); then it also attains its lowest noontime altitude. In order to avoid confusion, only the important daily solar paths are depicted in Fig. 24 (the path on zenith passage dates will be referred to later). Approximate solar declinations for different dates of the year are listed in Table 11.

The rhythmic oscillation of the sunrise and sunset points along the local horizon afforded the ancients a convenient method for establishing an annual calendar. In fact, the horizon may be treated as a calibration device with prominent peaks and valleys serving as time markers. The cyclic motion, like that of a pendulum, is perfectly repetitive; furthermore, it is attuned to the seasons. Little wonder the ancients regarded it as important. Next to the day-night cycle and the phases of the moon, the annual oscillation of the sun along the horizon is one of the most universally recognized periods occurring in the natural environment.

Since we have reason to believe that ancient people may have utilized solar horizon observations, a further discussion of this motion may be helpful for our future considerations. In high latitudes, such as that of Stonehenge (51° N), where changes in the annual solar motion at horizon are great, the daily shift of the position of sunrise or sunset is more easily noted. In low latitudes, such as those inhabited by the civilizations of Mexico (20° N) and Peru (15° S), the range of horizon covered annually by sunrise and sunset points is smaller, and, consequently, the daily change is less. Fig. 25 contrasts the horizon extremes at Stonehenge and Teotihuacán on the same scale. Identical hypothetical horizons are used in the comparison, though the size of the sun is exaggerated.

Fig. 25 also shows that the sun's "horizon points" do not change at a uniform rate throughout the year. Around the time of the equinoxes, when the sun moves across the equator, its contact points with the horizon shift noticeably from day to day. Near the time of the solstices, when the movement of the sun along the ecliptic is more nearly parallel to the equator, the change is only very slight. These motions are contrasted in Table 2, which lists the azimuth of the center of the disk

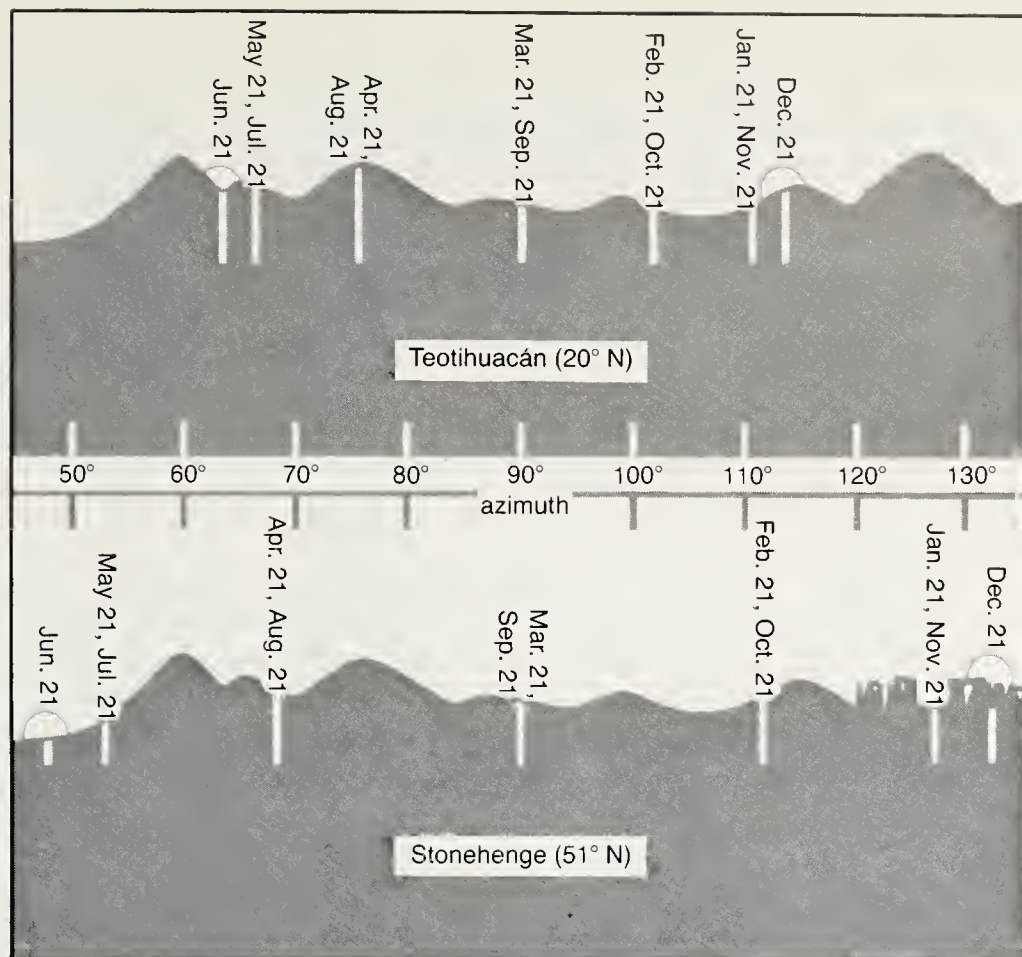


FIG. 25. Rising positions of the sun charted at monthly intervals throughout the year as viewed from Teotihuacán, Mexico (latitude, $19^{\circ}41' \text{ N}$), and Stonehenge in the southern British Isles (latitude, $51^{\circ}11' \text{ N}$). (Diagram by P. Dunham)

of the sun as it should have appeared on the astronomical horizon of an observer in latitude 20° N around the time of the vernal equinox (A) and near the summer solstice (B). The data include, for a given date, the declination of the sun, taken from the *American Ephemeris and Nautical Almanac*, year 1973; the calculated azimuth; and, in the last column, the change of azimuth between successive dates. We see that around the time of the vernal equinox the horizon points of the sun moved nearly a full solar diameter (30 minutes of arc) per day. Note also that the equinox for the year 1973 occurred some time between March 20 and 21 (actually it occurred at the instant the sun's declination changed from $-$ to $+$). This is exactly when the greatest solar motion occurred parallel to the horizon. However, at the summer solstice the situation was very different. Rising around azimuth 65° (25° N of E) the sun hardly altered its rising point during the week encompassing June 22; in fact, between June 21 and 22 it changed by less than $1/10$ of a minute of arc, about the diameter of a 50-cent piece at one kilometer. The word *solstice* is indeed an appropriate term to describe the behavior of the sun at this time of the year—it means “sun stand” in Latin.

Given their rudimentary measuring devices, how could the ancients detect daily changes in the position of the sun on the horizon,

Table 2. *The Azimuth of Sunrise for an Observer in Latitude 20° N*

	<i>Date (1973)</i>	<i>Declination of Sun</i>	<i>Calculated Azimuth</i>	<i>Daily Change of Azimuth</i>
A. Near the vernal equinox	Mar. 18	− 1°05'4	91°09'6	
	Mar. 19	− 0°41'7	90°44'5	25'1
	Mar. 20	− 0°18'0	90°19'3	25'2
	Mar. 21	+ 0°05'8	89°54'0	25'3
	Mar. 22	+ 0°29'5	89°28'7	25'3
	Mar. 23	+ 0°53'1	89°03'5	25'2
B. Near the summer solstice	Jun. 19	+23°25'3	64°58'9	
	Jun. 20	+23°26'1	64°57'7	1'2
	Jun. 21	+23°26'5	64°57'4	0'3
	Jun. 22	+23°26'6	64°57'4	0'0
	Jun. 23	+23°26'2	64°57'7	0'3
	Jun. 24	+23°25'3	64°58'9	1'2

Calculated using computer program in Appendix F; a 1° horizon elevation is assumed.

especially near standstills? We have already seen suggestions in the ancient literature which imply that crossed-sticks were used to mark the azimuth of rising and setting celestial objects (Fig. 5). These simple sighting devices may have consisted of a pair of sticks, one used as a foresight and the other as a backsight. The scheme is illustrated in Fig. 26. Actually, a distant point in the landscape could serve equally well as a foresight. These sticks could be used to mark a solar alignment on a particular day in the year. As the year progressed and the sun migrated away from the mark, it would be carefully watched. When it returned from the same direction to the original position in the notches, a solar cycle would have been completed.

If a skilled observer employed a distance of 100 meters between foresight and backsight, he could determine the difference in azimuth of sunsets on a pair of successive days around the equinoxes (about one solar diameter) by shifting his back sticks horizontally about 80 cm between dates. If he were delegated the same task around the solstice, the movement of the sticks would necessarily be about one hundred times smaller, as Table 2 suggests. The observer would need to lengthen the base line by a suitable factor; for example, Table 2 tells us that a lateral shift of the same magnitude at the solstices would require a base line several kilometers long.

The modern experimenter who tries to duplicate ancient solar observations is immediately beset with the problem of the definition of sunset. Is it the point at which the lower limb of the sun's disk is tangent to the observer's horizon? Or the geometric center of the disk? Perhaps the easiest point to measure is the last gleam of sunset, when the upper limb disappears over the horizon. Certainly this would be

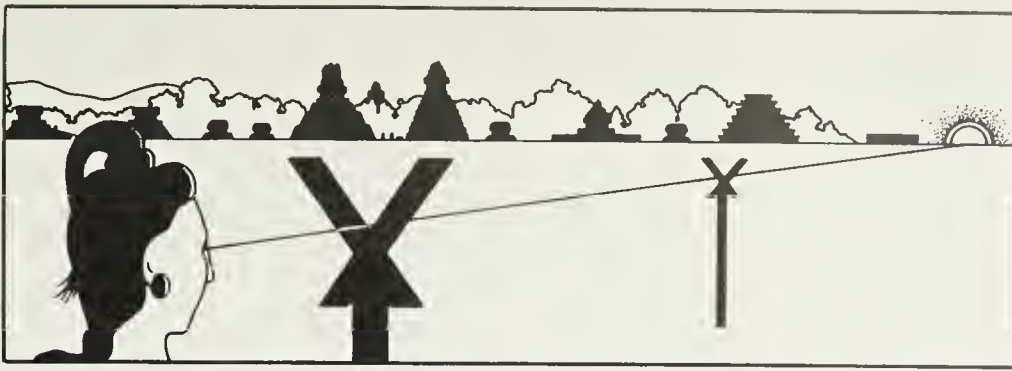


FIG. 26. Fixing the sunrise by using a pair of crossed-sticks. (Diagram by P. Dunham)

most noticeable. Assuming modern observers are as careful as the ancient astronomer-priests who used the stick sighting method, we can see why the solstice would have appeared to be a real solar "standstill." Perhaps this crucial turning point in the solar path was calculated from a count of the number of days the sun took to depart from and return to a fixed point on the horizon a few degrees removed from the solstice.

Because the earth travels about the sun at varying speeds on an elliptical orbit, the sun appears to move slightly faster during the winter months when the earth and sun are closer together. The interval between autumnal and vernal equinox is approximately eight days shorter than the other half of the year.⁵ Thus, if ancient astronomers had operationally defined the equinoxes as the midpoints *in time* between the solstices, rather than by the rising and setting of the sun at the east and west points of the horizon, the sun would rise about three of its own diameters north of the east point and it would set the same distance north of the west point on these important dates. This might seem trivial, but such a scheme would not be unreasonable if an ancient astronomical system based on horizon observations were to have developed. In this case, an axial coordinate system utilizing the four "cardinal directions" might not be perfectly rectangular, a consideration which should be taken into account in any discussion of astronomical orientations.

We know that the solstice and equinox horizon points undoubtedly functioned in the establishment of a seasonal calendar. Are there any other sun positions worth considering? The ethnohistorical record in Mesoamerica suggests that the passage of the sun through the zenith may have been used to fix dates in the agricultural calendar; the horizon points for the sun on those days also may have been noted. The passage of the sun across the zenith is a phenomenon that occurs only in tropical latitudes. In Fig. 24 the sun is shown attaining the zenith, Z, at a tropical northern latitude. The diagram suggests that this occurs several days before the summer solstice. For simplicity, suppose that on June 22 the sun reached the zenith precisely at noon. What is the latitude of the observer (NP) for this situation? By inspecting the diagram we note that the arc QZ must be equal to the arc NP, because POQ is a right angle. (Q is the point of intersection of the celestial equa-

good insight.

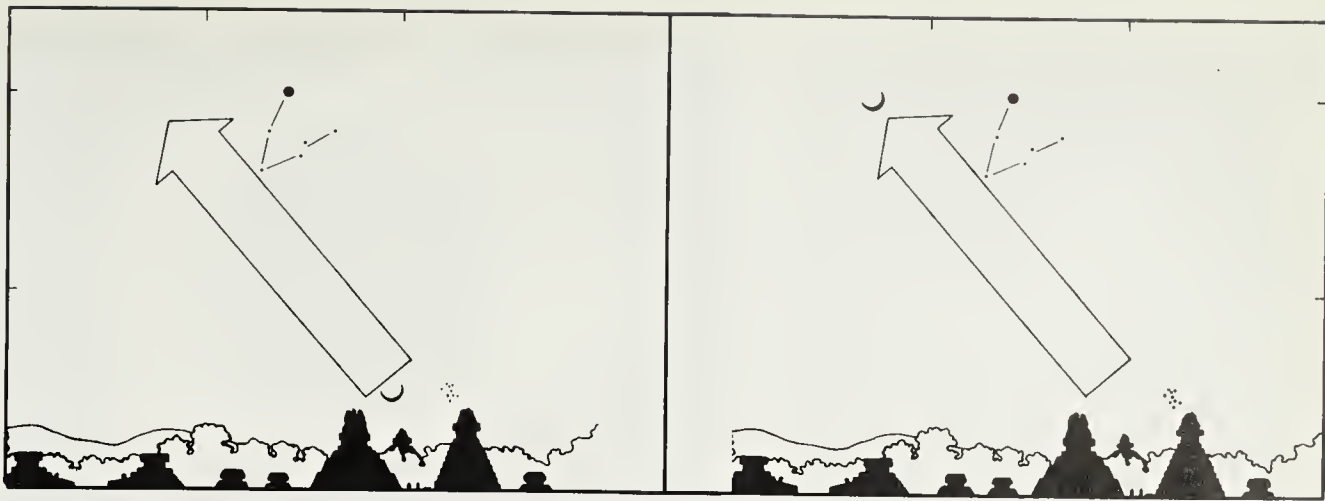
Table 3. Zenith Passage Dates of the Sun for Observers in Different Latitudes

<i>Latitude</i>	<i>Dates</i>	<i>Number of days N/S of Zenith</i>
23½°N	Jun. 22	1/364
20°N	May 21, Jul. 24	64/301
15°N	May 1, Aug. 12	103/262
10°N	Apr. 16, Aug. 28	134/231
5°N	Apr. 3, Sep. 10	160/205
0°	Mar. 21, Sep. 23	186/179
5°S	Mar. 8, Oct. 6	212/153
10°S	Feb. 23, Oct. 20	239/126
15°S	Feb. 8, Nov. 3	268/97
20°S	Jan. 21, Nov. 22	305/60
23½°S	Dec. 21	364/1

See also Table 11.

tor with the celestial meridian.) Since NP represents the altitude of the pole as well as the latitude of the observer and QZ is the declination of any object located at the zenith, we see that the observer's latitude for this situation must be $23\frac{1}{2}^{\circ}$ N. Since the declination of the sun can never exceed $+23\frac{1}{2}^{\circ}$, we see that, in fact, the sun can reach the overhead position only for observers situated between latitudes $23\frac{1}{2}^{\circ}$ N and S ($23^{\circ}27'.1$ at present to be exact). At either the Tropic of Cancer (latitude $23\frac{1}{2}^{\circ}$ N) or the Tropic of Capricorn (latitude $23\frac{1}{2}^{\circ}$ S) the sun will reach the zenith on one day of the year only. Zenith passages occur on June 22 at the Tropic of Cancer and on December 22 at the Tropic of Capricorn. In Chapter V we discuss certain markers which may have been placed at the Tropic of Cancer in recognition of the passage of the sun through the zenith precisely at the summer solstice. On these dates, a vertical stick, or gnomon, in the respective locations will cast no shadow at noon. For observers between the tropics there will be two zenith passage dates equally spaced about the solstices, one occurring on the day the sun crosses the zenith as it goes northward along the ecliptic, the other as it returns southward. For observers closer to the earth's equator, these dates occur further in time from the solstices than in latitudes approaching $23\frac{1}{2}^{\circ}$. For a person situated exactly on the equator, the zenith passage dates will coincide precisely with the vernal and autumnal equinox dates. Table 3 gives, for various latitudes, the zenith passage dates as well as the number of days the sun spends north and south of the zenith in a given calendar year.

The dates and intervals associated with latitude 15° N are of particular interest since they may be tied to the origin of the sacred Maya 260-day count (see Chapter IV). The elliptical shape of the earth's orbit produces noticeable inequalities between latitude pairs of opposite sign. Perihelion passage, or the point on the earth's orbit nearest the sun, occurs about January 2; since the earth moves faster at this time, the solar motion along the ecliptic appears most rapid to us then.



Box C

Other important solar events likely to have been recorded by ancient civilizations include sunset in a particular direction or on a special date in the solar year. Some useful calculations relating to such solar phenomena are delineated in Appendices C and D.

THE MOON, ECLIPSES, AND ECLIPSE CYCLES

Compared with the simple annual oscillating motion of the sun, the apparent motion and cyclic changes of the moon are complex. It is perhaps this very reason which led the ancients to expend so much energy trying to comprehend its motion. For the ancients, the moon seemed never to be on time and this was usually construed as a bad omen. The shortcomings of chronology evolved into a means of prediction for the ancient astrologer.

Phases were surely the most obvious lunar aspect to register in the mind of archaic observers. In Western lore they depict the career of the Man in the Moon (see Fig. 27f). He begins his adventure when the waxing crescent first appears by fighting the devil of darkness, a dragon, who has eaten up his father, the old moon. No sooner does he reach the zenith of power than the old enemy who conquered his father begins to attack him. But for ancient Americans a rabbit adorned the face of the moon (Fig. 27e). The gods were said to have played tricks on the moon and struck him in the face with a rabbit, but afterward he came forth to light up the world (Sahagún, 1953, p. 42).

In Fig. 28 the lunar phase cycle is depicted, while Fig. 29 shows how phase changes are actually viewed in the heavens. These illustrations may be used together to follow the phase cycle through one month. In Fig. 28 the direction to the sun, which always lights half the moon, is imagined to be held fixed far right of the page as the moon circles the earth. The portion of the lighted half visible from earth is illustrated inside the orbit for various positions.

After being lost in the glare of the sun to a naked-eye observer for



a



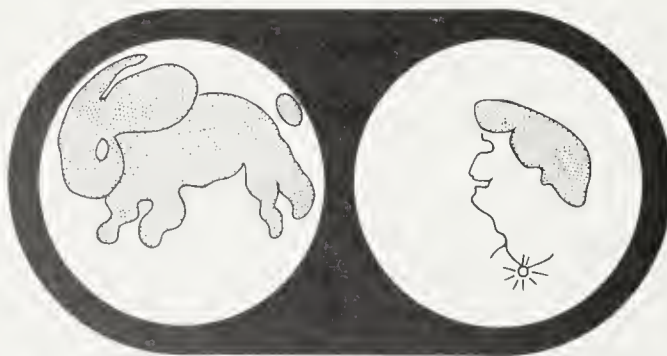
b



c



d



e

f

FIG. 27. Solar and lunar eclipses: (a) Partial eclipse of the sun. The new moon has removed about one-third of the visible solar surface as it passes between the earth and the sun. (b) Total eclipse of the sun. Observers fortunate enough to be in the proper location at the correct time will witness complete coverage of the solar disk, thus revealing the pale light of the sun's corona surrounded by a darkened sky sprinkled with bright stars. See FIG. 9 for depictions of this event in the codices. (c) Partial eclipse of the moon. The earth's shadow creeps across the lunar surface covering about two-thirds of it in this picture. (d) A total eclipse of the moon often reveals a blood-red cast to the lunar disk. The depth of color changes from eclipse to eclipse, depending upon the condition of the earth's atmosphere. The Mesoamerican rabbit in the moon (e) along with our Western man in the moon (f) are sketched from the photos (diagrams by P. Dunham). They are more easily recognized with the naked eye (cf. FIG. 61b).

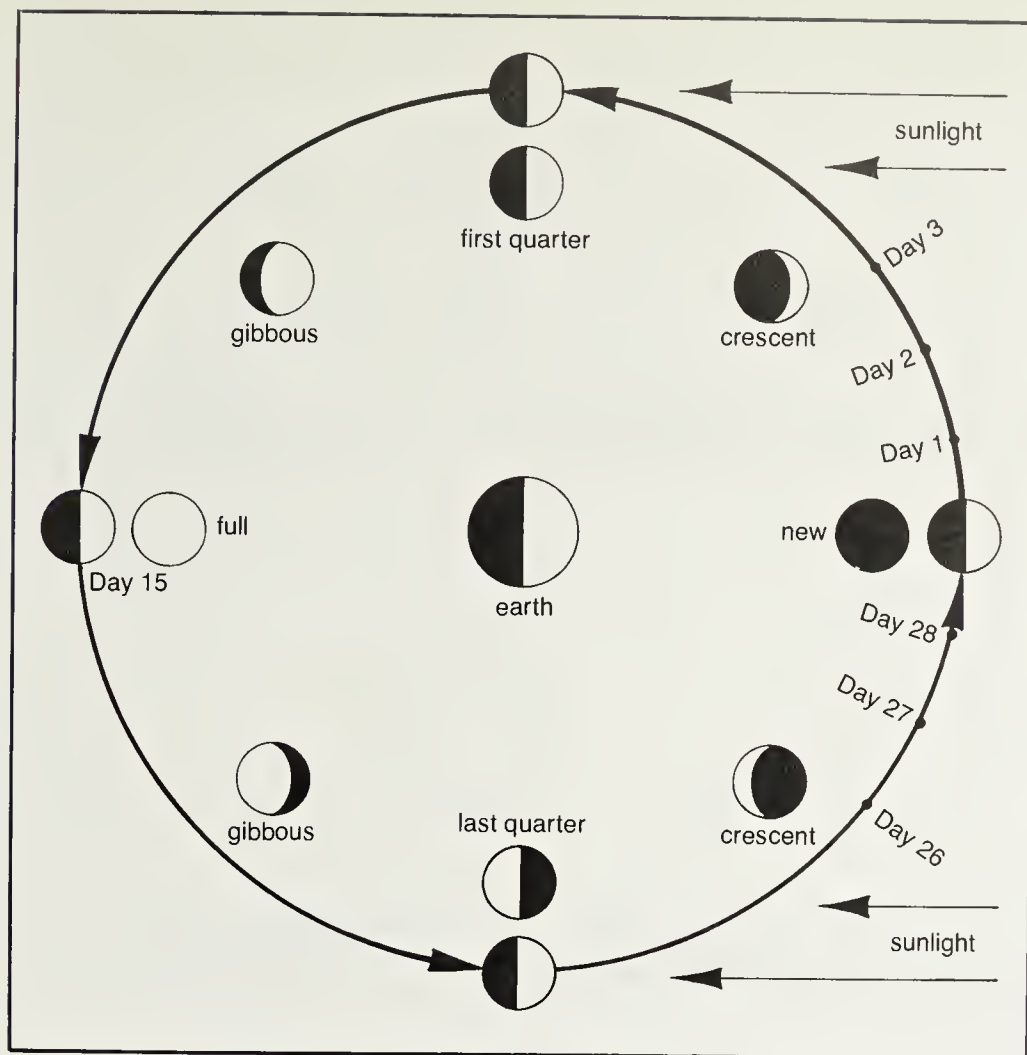


FIG. 28. Cyclic phases of the moon result from the exposure of the earth-based observer to different percentages of the sunlit portion of the moon. The cycle is completed in approximately $29\frac{1}{2}$ days. The motion of the moon is depicted by the heavy arrows while the pictures within show the aspect of the face of the moon at that point of the cycle. (Diagram by P. Dunham)

two or three days, the moon is first seen as a thin crescent in the west at twilight close to the position of sunset. On this occasion (Day 1 in both figures), it is visible for only a few fleeting moments as it follows the sun downward below the darkening horizon. By the next night the moon has shifted in its orbit to a position where the angle (an arc on the sky) between it and the sun, as seen from the earth, has increased (Day 2). Consequently, we see a slightly thicker crescent a bit farther removed from the sun for a longer period of time (Day 2). By the third night (Day 3) the moon has moved far enough from the sun to remain visible as a well-defined thick crescent for about an hour or two after sunset. A little over seven days past new moon the angle between the moon and the sun is about 90° . It has waxed to first quarter (i.e., we see half the disk) and reaches its highest altitude on the celestial meridian at sunset. As it approaches full phase (Day 15 in Fig. 28) during the next week, it rises progressively earlier, first appearing at sunset, opposite

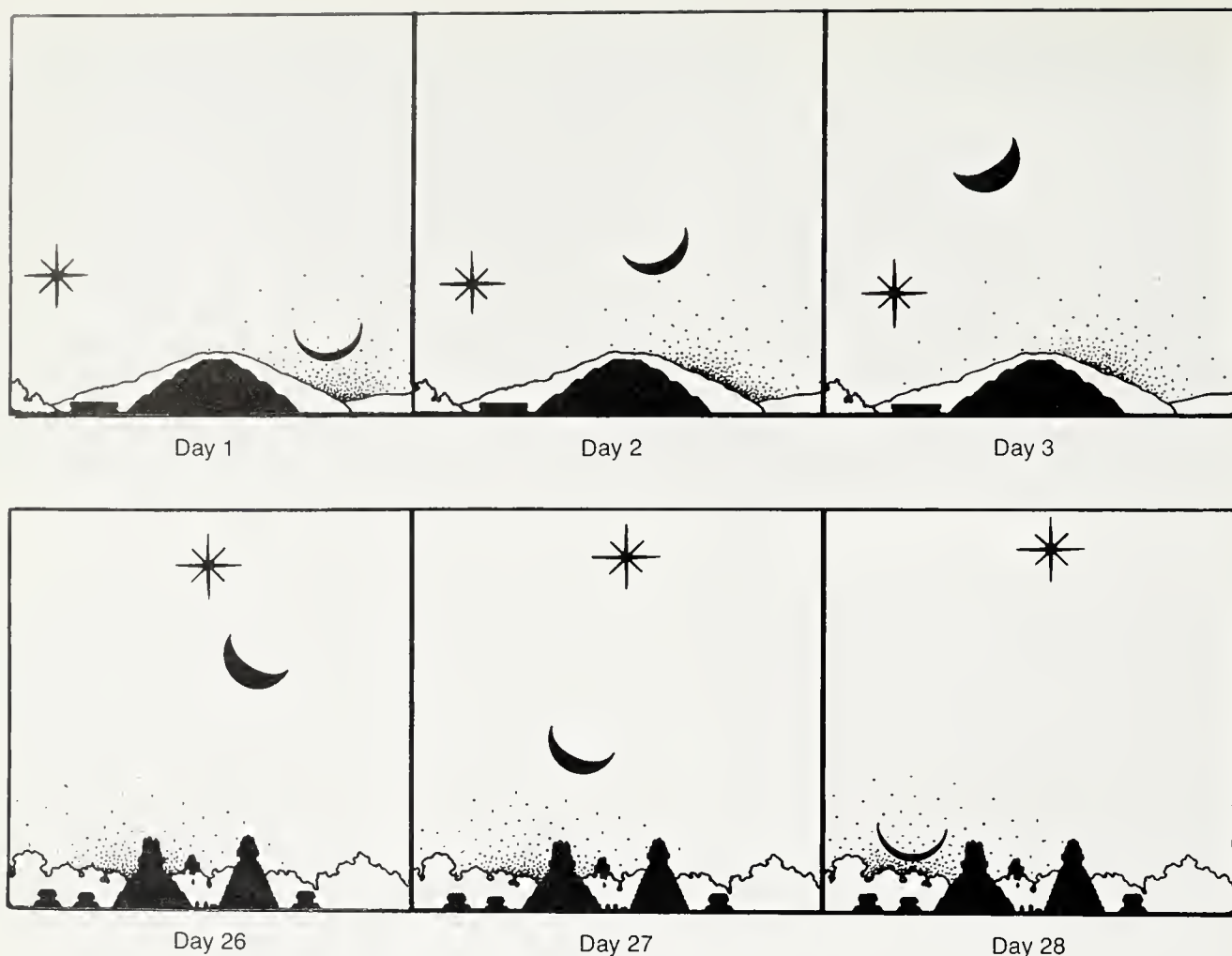


FIG. 29. The crescent moon as it actually appears in the western sky one hour after sunset on three successive nights (Days 1, 2, 3). Note that the lunar crescent begins to fill out or "wax" as it passes upward toward a star (which scarcely seems to move relative to the sun). At the end of the month the waning crescent moon is pictured in the east before sunrise on three successive days (Days 26, 27, 28) of the lunar phase cycle. It passes below another star as it approaches the sun. On the twenty-ninth day it enters the new phase and becomes invisible as it is lost in the light of the sun. Approximate positions of sunrise and sunset are indicated by the twilight glow. (Diagrams by P. Dunham)

the sunset point when it is full. During the second half of its phase cycle, the moon wanes, being visible only in late evening and early morning skies and, toward the end of its cycle, in the daytime. In Fig. 29 three pictures show the thinning crescent approaching the sunrise position on successive days toward the end of a lunar month. On Day 29 (not shown) the moon once again passes into the glare of the sun and the cycle is renewed as the moon reappears in the evening sky.

Though the phase cycle was universally recognized, ancient astronomers recorded it in different ways. Usually, it was tallied as a 29- or 30-day period beginning with the first appearance of the thin waxing crescent, but often the month was counted from new to new and even from full to full phases. In Chapter IV we shall see that the Maya suc-

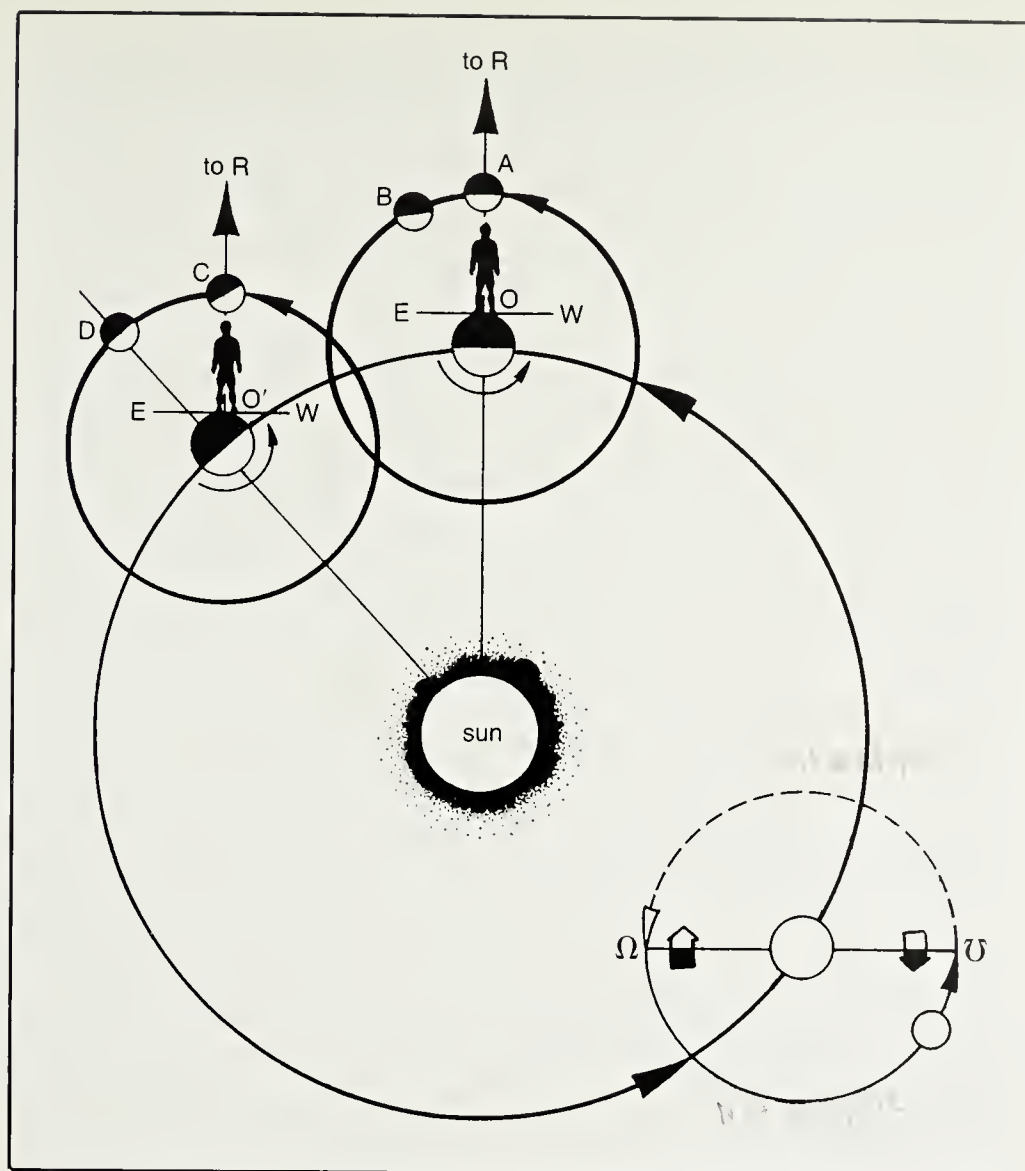


FIG. 30. Our Western version of the many motions of the moon. The earth's orbit about the sun is the large circle, the moon's orbit about the earth the smaller ones. For simplicity in following the discussion given in the text, imagine that the observer is standing on a flat board that represents the horizon. The diagram in the lower right depicts the regression of the lunar nodes. (Diagram by P. Dunham)

ceeded in measuring the lunar month with great accuracy. Among the American Indians of the southwest the *visible* moons in a cycle were named, thus the number 28, not 29 or 30, appears as their most important lunar count (see, e.g., the discussions of Casa Rinconada and the Medicine Wheel in Chapter V).

Fig. 30 will help demonstrate why the moon appears to move relative to the sun and stars at different rates. In this diagram suppose that a straight line connects the moon, the earth, and the sun and that an observer at O on the surface of the earth views the moon at position A in his zenith (EW is his horizon plane). Since the moon is directly opposite the sun along the line AO at this time, the observer will see a full moon. Suppose further that at this time the moon occults a distant

star, R.⁶ A day later the observer has undergone one full rotation on the surface of the earth (clockwise in the diagram) and the star R has returned to his zenith. In the meantime the moon has moved slightly east of its original position to point B. The observer sees it fall a little behind the position of the star, rising progressively later than the star (about $\frac{3}{4}$ of an hour later per day). The next alignment of the observer, the moon, and the star will occur when the earth is at position O'. Then he sees the moon at position C in his zenith. Since the distance from the earth to the star is millions of times larger than that from the earth to the sun, the directions OA and O'C to the star are reasonably parallel. The interval between successive passages of the moon by the same star is called a *sidereal month* from the Latin word *sidus*, meaning star; that is, it is a month as measured by the stars. Modern astronomers have determined the length of the sidereal month to be 27.32166 days. Thus, if the moon appears in a certain position in the constellation of Taurus this evening, the observer may be assured that it will return to the same position after $27\frac{1}{3}$ days.⁷ However, because of the fractional number of days involved in the sidereal period, the moon will assume that position $\frac{1}{3}$ of a day (8 hours) later in the evening. If the observer makes this evening's observation at midnight, he or she should make the second observation one sidereal month later at 8 A.M., after the sun has already risen and the background stars are no longer visible. From a purely empirical point of view, it might be convenient to think of sidereal months as occurring in groups of three. Thus, after a period of $3 \times 27\frac{1}{3} = 82$ days the moon will assume its original position in Taurus *at the same time of the night*. When charting the motion of the moon among the constellations, ancient astronomers may have seen greater importance in the 82-day period as a matter of simple convenience than in the $27\frac{1}{3}$ -day interval.

While the moon, earth, and star have realigned after one sidereal month, it will take longer for the moon, earth, and sun to come back into line. This will not happen until the moon has traced out the arc CD. The moon, having completed a cycle of its phases, is now full again. The interval between successive full moons is called a *synodic month* (a month relative to the position of the sun). We should expect from the diagram that the synodic interval will be longer than the sidereal. In fact, its length from modern determinations is 29.53059 days, a little more than two days longer. The synodic month is also termed the "month of the phases" from which we derive our modern, if somewhat inaccurate, calendar month (a contraction of "moonth").

With some understanding of the difference between the synodic and sidereal periods of the moon, we are now able to analyze the workings of one of the grandest of nature's phenomena—eclipses. Fig. 27 provides a synopsis of views of lunar and solar eclipses, both of which must be witnessed to be appreciated. If the plane of the moon's orbit about the earth coincided with that of the earth's orbit around the sun, an eclipse of the moon would occur at every full moon when the three aligned exactly. Solar eclipses would occur two weeks later at new moon when the moon lies between the earth and the sun. But the orbit of the moon is inclined by $5^{\circ}09'$ to the ecliptic plane. At the lower right of Fig. 30 the lunar orbit is pictured again. Let the plane of the earth's

orbit be represented by the plane of the paper. The dotted portion represents that half of the moon's orbit buried below the plane of the paper, that is, when the moon lies south of the ecliptic; the solid portion represents the orbital segment lying above the plane of the paper, when the moon is north of the ecliptic. The intersecting points of the ecliptic and the lunar orbit are called the *ascending* (Ω) and *descending* (Υ) *nodes* of the moon's orbit, and the line connecting them is termed the *line of nodes*.

A terrestrial observer situated at the center of the lunar orbit sees the moon oscillate back and forth across the ecliptic, extending as far as $5^{\circ}09'$ north of the ecliptic and the same angular distance south. Suppose that the sun is at the summer solstice when the moon attains its greatest northerly position relative to the ecliptic; then the lunar declination will reach a maximum: $+23^{\circ}27' + 5^{\circ}09'$, or $+28^{\circ}36'$. Conversely, the southern limit, which would coincide with a new or full moon at the winter solstice, is $\delta = -28^{\circ}36'$. These limits are also called "standstills" in the literature. A tiny wobble in the lunar orbit with a period of 173 days can extend the range $9'$ farther in either direction.⁸ Though the 5° motion is easily detectable, we can apply the crossed-stick sighting principle discussed earlier to deduce that such a tiny motion as the $9'$ wobble would be detectable only with a very long distance base line and repeated observation. Conceivably, the timing of the wobble could provide an excellent means of predicting eclipses, but the Maya had an easier way, as the written record discussed in Chapter IV shows.

How often does the moon attain its standstills? Evidently, every time the nodes coincide with the equinoxes. But the line of nodes undergoes an east-to-west motion, making one full circuit on the ecliptic in 18.61 years. Since this motion is contrary to the west-east (counterclockwise) direction of the other motions depicted in Fig. 30, it is termed the *regression of the nodes*. Thus, the extreme declinations and, consequently, the extreme northerly and southerly setting positions of the moon along the local horizon are reached at $18\frac{2}{3}$ -year intervals. Extremes last occurred in mid-1969 and will not be reached again until late 1987.

An eclipse occurs only when a new or full moon lies close to one of the nodes of its orbit. In the former case we will have an eclipse of the sun, while the latter will produce a lunar eclipse. In Fig. 31, the sun, the earth, and the moon (both greatly exaggerated in size) are nearly aligned. The moon is represented at two positions, M and M', in its orbit. For the case shown, the line of nodes ($\Omega\Upsilon$) coincides with the line connecting the earth to the sun. When the new moon is at M, the tip of the umbra, or dark central portion of its shadow, is about to touch down on the earth, thereafter describing an arc over the globe. Because the length of the moon's shadow is approximately equal to the distance from the earth to the moon, the width of the arc will be very narrow. Terrestrial observers lying within the narrow shadow zone will see a total eclipse of the sun, while those situated in the penumbra, or lighter portion of the shadow, will experience a partial solar eclipse.

Since the earth-to-moon distance varies, the tip of the umbra may on occasion fall short of the earth's surface. Then, the disk of the new

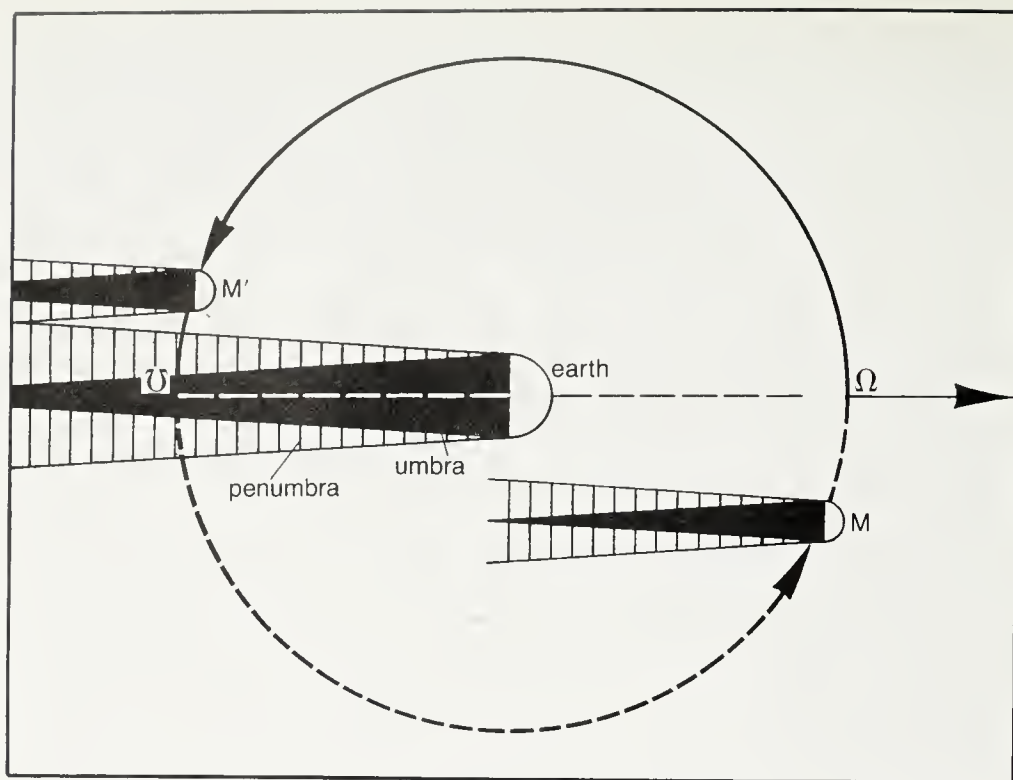


FIG. 31. Circumstances for a solar eclipse (moon at M) and a lunar eclipse (moon at M'). An eclipse can take place only when the nodes of the moon's orbit (Ω , U) align with the earth and sun. (Diagram by P. Dunham)

moon will not quite cover the sun and an *annular* eclipse of the sun will result. Such an eclipse receives its name from the appearance of a bright ring, or annulus, of sunlight appearing about the darkened disk of the sun at totality. When the moon is nearest the earth, the shadow umbra attains its maximum width, approximately two hundred miles at the earth's surface. Then the lunar disk easily covers the solar surface and the sun may be totally eclipsed for as long as seven minutes; this occurred in 1973.

When the moon is on the opposite side of the earth relative to the sun, a different phenomenon occurs. At M', the full moon, having already entered the penumbra, or lighter portion, of the earth's shadow, is about to pass into the umbra, at which time the moon will be totally eclipsed. The earth's shadow is approximately three times longer than the distance between the earth and the moon. At the position of the lunar orbit, the shadow width is nearly triple the lunar diameter. (This has been de-emphasized in the figure.) As a result, a considerable time is required for the moon to pass through the shadow. About an hour will lapse between the time when the earth's shadow bites into the disk of the moon and the moon is fully eclipsed. Then it is illuminated only by the spectrum of light refracted through the earth's atmosphere and it shines dimly, taking on a somber reddish hue. We discover that, while a solar eclipse is a fleeting occurrence visible only in the narrow geographical area where the moon's pencil-point shadow strikes the earth, a lunar eclipse, from the commencement of partial phase when

Eclipse prediction was a great challenge for the ancient astronomers. The fear engendered by the departure from the regularity of nature epitomized in the eclipse was as real then as is our present fear of nuclear war.⁹

1. Once a lunar eclipse takes place, a second one never follows at an interval of less than six months.
2. The second lunar eclipse is usually followed by a third after another six-month interval.
3. Series of three, four, or five lunar eclipses follow each other in the manner indicated, for example:

(Series I)

(Series 2)

(Series 3)

- Thus, if the ancients observed an eclipse which was *not* preceded by another six, twelve, or eighteen months earlier, they knew a new series had started and they would be able to *foretell* that future eclipses would occur in six and, probably, twelve months. Of course, we must realize that the longer a tradition of skywatching persists within a culture, the better the chance of detecting eclipse cycles and periodicities. Solar eclipses, being rarer, are harder to spot, the frequency of observation depending upon how scanty a partial eclipse would be noted—an

Table 4. Eclipses of the Sun and Moon during the 1980s

<i>Date</i>	<i>Type</i>	<i>Number of Days to Next Eclipse</i>	<i>Phase</i>	<i>Region of Visibility of Annular or Total Solar Eclipses†</i>
1980 Feb. 16	Solar	176	Total	North Atlantic, Central Africa, India, China
Aug. 10	Solar	178	Annular	Central Pacific, Central South America
1981 Feb. 4	Solar	163	Annular	South Pacific
Jul. 17	Lunar	14	Partial	
Jul. 31	Solar	162	Total	Caspian Sea, Siberia, North Pacific
1982 Jan. 9	Lunar	16	Total	
Jan. 25	Solar	147	Partial	
Jun. 21	Solar	15	Partial	
Jul. 6	Lunar	14	Total	
Jul. 21	Solar	148	Partial	
Dec. 15	Solar	15	Partial	
Dec. 30	Lunar	163	Total	
1983 Jun. 11	Solar	14	Total	South Indian Ocean, Malaysia, New Zealand
Jun. 25	Lunar	162	Partial	
Dec. 4	Solar	178	Annular	North Atlantic, Central Africa
1984 May 30	Solar	175	Total-Annular*	Central Pacific, Northern Mexico, Southern United States, North Atlantic, North Africa
Nov. 22	Solar	163	Total	New Zealand, South Pacific
1985 May 4	Lunar	15	Total	
May 19	Solar	162	Partial	
Oct. 28	Lunar	15	Total	
Nov. 12	Solar	148	Total	South Pacific, Antarctica
1986 Apr. 9	Solar	15	Partial	
Apr. 24	Lunar	162	Total	
Oct. 3	Solar	14	Total	Greenland, Iceland
Oct. 17	Lunar	163	Total	
1987 Mar. 29	Solar	178	Total-Annular*	Southern South America, South Atlantic, Central Africa
Sep. 23	Solar	14	Annular	Central Asia, China, South Pacific
Oct. 7	Lunar	163	Partial	
1988 Mar. 18	Solar	162	Total	Malaysia, Coastal East Asia, Aleutian Islands
Aug. 27	Lunar	15	Partial	
Scp. 11	Solar	162	Annular	West Africa, South Indian Ocean, Australia
1989 Feb. 20	Lunar	15	Total	
Mar. 7	Solar	163	Partial	
Aug. 17	Lunar	14	Total	
Aug. 31	Solar		Partial	

* Total for part of the path and annular for the remainder.
† All other eclipses visible over a much wider area.

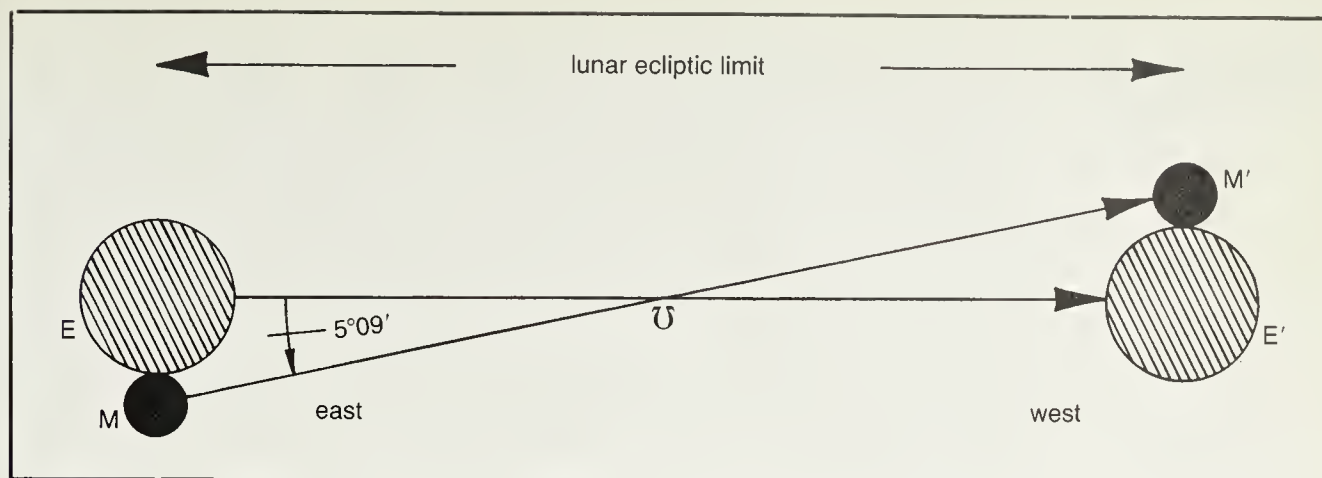


FIG. 32. The region of the descending node of the moon's orbit (MM') magnified to show the zone along the ecliptic (EE') within which an eclipse of the moon can take place. The lunar ecliptic limit extends twelve or thirteen days either side of node passage. (Diagram by P. Dunham)

uncertain quantity. Ultimately, all ancient astronomical systems derive from the ancient astronomer's data bank. We must constantly try to view events through their eyes.

If we begin to examine in detail the circumstances under which eclipses occur, we are treated to a wealth of fascinating naked-eye observations about them. In order to determine more precisely the frequency of occurrence of eclipses, we deviate to the diagram of Fig. 32 from Western astronomy, in which we magnify the region around the descending node at the time of a lunar eclipse. Then we return to examine the eclipse cycles thus derived. The orbital planes are now shown perpendicular to the paper. MM' is a segment of the lunar orbit, with the moon entering the picture at the upper right (west); EE' is a portion of the ecliptic. The cross-section of the earth's conical shadow, a circular dark spot traveling along the ecliptic opposite the sun, is seen entering the picture at the right, also moving from west to east; U is the descending node. The configurations of the moon and the earth's shadow, shown at opposite ends of the figure, are barely compatible with the occurrence of an eclipse of the moon because the two just touch in either case. Thus, the lunar disk and the earth's shadow need not coincide precisely at the node in order to produce an eclipse. The *lunar ecliptic limit* is defined as the zone about the node within which an eclipse of the moon may occur. Given that the size of the lunar disk is $\frac{1}{2}^\circ$ and the diameter of the earth's shadow at the distance of the moon is approximately $1\frac{1}{2}^\circ$, a simple geometrical calculation will show that the lunar ecliptic limit (spanning both sides of the node) is an arc of the ecliptic approximately 25° long or nearly 7 percent of the length of the ecliptic. Now, the earth's shadow passes eastward along the ecliptic at the rate of 1° per day, imitating the motion of the sun. Thus, it takes 25 days to cross the lunar ecliptic limit. If a full moon is encountered on any one of those days, that is, within 12 or 13 days of its passage by the node, it will be eclipsed. But a full moon occurs every $29\frac{1}{2}$ days. Consequently, it is possible for the earth's shadow to enter and leave the lunar ecliptic limit while the moon lies completely out-

side the eclipse zone. We conclude that a lunar eclipse need not occur at every nodal passage but that one *may* occur.

The situation is different for solar eclipses. The *solar ecliptic limit* is a region 31° long within which the sun and the new moon must be situated in order to produce a solar eclipse. Since the sun takes longer than $29\frac{1}{2}$ days (the interval between new moons) to traverse the solar ecliptic limit, we conclude that there must be a solar eclipse every time the sun passes a node and, furthermore, that there can be a pair of eclipses of the sun one synodic month apart at the same node. Eclipses of the sun, contrary to popular belief, are more common than eclipses of the moon. We must remember, however, that the viewing audience for the lunar event is considerably larger.

Let us illustrate these principles with a specific example. Suppose that the sun is near the descending node on January 1 of a given year and that a lunar eclipse takes place on that date. The next time a lunar eclipse can occur, the sun will be at or near the ascending node. But the nodes regress opposite the direction of motion of the sun, completing a circuit in 18.6 years. In one year they will have moved $\frac{1}{18.6} \times 360^\circ$, or 19.4° westward. Thus, the sun will arrive back at the descending node about 19 days short of a year later, or 346 days later. It will arrive at the ascending node 173 days after January 1, or June 22; around this time the second lunar eclipse of the year would occur. A third eclipse may happen about December 12, 346 days after January 1. Consequently, as many as three lunar eclipses can occur in a given calendar year.

Assuming instead that our January 1 eclipse were solar, we might find a second eclipse of the sun occurring at the next new moon, about January 30, before the sun could slide off the edge of the solar ecliptic limit. This would be a likely occurrence should the January 1 eclipse have occurred at the western end of the ecliptic limit. The next pair of solar eclipses would occur about June 22 and July 21 and another set could be observed around December 12 and January 10. Since the latter date occurs in the next calendar year, we conclude that no more than five solar eclipses can occur in a given year, while the minimum number is two, one on each of the first new moons occurring at the given nodal passages. Rarely are these extreme conditions met and frequently many of the eclipses turn out to be only partial.

There are thirty-five eclipses listed in Table 4 scheduled to occur in the 1980s, twenty-two of which will be solar. Of the solar eclipses, fourteen will be total, five of them annular. Two eclipses will be viewed as annular over part of the path of totality and total over the remainder. 1982 will be the most propitious year of the decade for eclipses with a total of seven, three lunar and four solar. That year will begin with a lunar eclipse near the ascending node on January 9. Two weeks later at new moon, with the sun at the same node, a partial eclipse of the sun will occur. When the sun reaches the eclipse region near the descending node, three eclipses will occur, a pair of solar eclipses at new moons on June 21 and July 20 and a lunar eclipse at the full moon midway between the two (July 6). Both solar eclipses will be partial, the first taking place when the sun is west of the node, the second when it is well to the east. Finally, the sun returns to the ascending node at the end of the year and two more eclipses take place. By con-

trast, 1980 will be the leanest eclipse year of the decade with only two eclipses, both solar.

To further illustrate the potential predictive power of the eclipse data bank, let us briefly examine the number of days lapsing between the eclipses listed in Table 4. The intervals, which are tabulated in the third column of that table, can be divided into four groups: 163 ± 1 , 148 ± 1 , 177 ± 1 , and 14 or 15 days. Given the foregoing discussion of the conditions needed to produce eclipses, we ought not be surprised to find such intervals showing up. The last is one-half of a synodic period and the rest are integral and half-integral multiples of the synodic month. The 177-day interval represents 6 moons, 163 days is $5\frac{1}{2}$ moons, and 5 moons are equivalent to 148 days. As we shall see in Chapter IV, the Maya employed an alternating count of 5 and 6 moons to warn of the possible occurrence of eclipses.

The three large intervals represent the integral and half-integral numbers of synodic months nearest the eclipse half-year of $173\frac{1}{3}$ days. This, it will be recalled, is the length of time required for the sun to pass from one node to the next. The interval between successive passages of a given node, 346 days, is called the *eclipse year*. As the table demonstrates, eclipses can occur only during "eclipse seasons" separated by approximately half an eclipse year. Notice that the times of nodal passage shift backward through the seasonal calendar, occurring during February and August early in the decade and in November and May in mid-decade. In 1989 the first season has backed up to August and the second to February. By 1998, one full nodal regression period after 1980, each of the seasons will have moved all the way backward through twelve months to assume its original position.

Our brief examination of the eclipse ephemeris for the 1980s demonstrates that by eclipse watching over a relatively short period one can learn a great deal about when eclipses can occur in the seasonal year and which new and full moons are most susceptible to becoming involved. That eclipses repeat in cycles extending over long periods of time was undoubtedly one of the most absorbing discoveries of ancient astronomy. Such a revelation must have required persistent observation and individual genius to find complex patterns emerging from the data. When whole multiples of the lunar and solar periods fit together, eclipses will repeat. Suppose that a full moon at one of the nodes is eclipsed. One synodic month later (29.53059 days) it is full again, but by that time it has already passed the node. The interval between successive passages of the moon by a given node is 27.21222 days. It is named the *draconic* month after the dragon who, the ancient Chinese believed, devoured the sun or moon during an eclipse. An eclipsed full moon will recur after a number of days equal to a whole multiple of the synodic and draconic intervals. If these periods were simple whole numbers, for example, 30 and 27 days, an eclipse would take place after 270 days (nine full moons or ten nodal passages). Actually, a half-integral multiple of the draconic month is also permissible since the moon may be eclipsed at the opposite node. There is no number fulfilling the desired condition perfectly, but some long intervals come close. In Table 5 we list several eclipse cycles derived simply by searching for close matches of integral multiples of synodic months with integral

Table 5. *Eclipse Cycles*

Days	Cycle Years	Number of Synodic Months	Number of Draconic Months
1,033.57	2.83	35	38.0
1,210.75	3.31	41	44.5
1,387.93	3.80	47	51.0
1,565.12	4.29	53	57.5
1,742.30	4.77	59	64.0
2,067.14	5.66	70	76.0
2,244.32	6.14	76	82.5
2,421.50	6.63	82	89.0
2,598.69	7.11	88	95.5
2,775.88	7.60	94	102.0
2,953.06	8.09	100	108.5
3,130.24	8.57	106	115.0
3,986.63	10.92	135	146.5
6,585.32	18.03	223	242.0
9,184.01	25.14	311	337.5
10,571.95	28.95	358	388.5
11,959.89	32.74	405	439.5
14,558.58	39.86	493	535.0
17,157.27	46.98	581	630.5
18,545.21	50.78	628	681.5
19,755.96	54.09	669	726.0
22,531.84	61.69	763	828.0
23,742.59	65.01	804	872.5
25,130.53	68.81	851	923.5
27,729.22	75.92	939	1,019.0

Adopted in part from Colton and Martin, 1967, p. 476.

and half-integral numbers of draconic months. For cycles of a decade or less, a tolerance of one day has been allowed in the computations. A selection of the most accurate longer cycles is also included.

Any of these intervals could have been recognized by the ancients, though some cycles might have been more easily detectable than others. Several may have been known to the Maya, as we shall see when we examine a Maya eclipse table in Chapter IV. The most famous of all the eclipse periods is the 6,585.32-day cycle. It was discovered by the ancient Chaldeans and later named the *saros*, meaning repetition (O. Neugebauer, 1975, 1:486). Counting forward 223 new moons from the time of a solar eclipse, we would expect another solar eclipse to occur since the saros interval is also a whole number of draconic months, 242 to be exact. If the first eclipse took place exactly at the node, the second would occur shortly before the moon arrived at its node because 242 draconic months is actually about one hour longer than 223 synodic months. Thus, the new moon will be one hour (about $1/2^\circ$) short of arrival at the node on the occasion of the second eclipse. The third

eclipse in the series, 223 synodic months later, will occur a full degree (two lunar diameters) west of the node. After about thirty-five eclipses, the moon will slide off the end of the ecliptic limit, thus terminating a particular series. The saros is worthy of further attention since it is also nearly equivalent to a whole number of years. Thus, eclipses in the saros cycle are seasonal. This is also very nearly true for one or two other cycles given in the table.

Not all solar eclipses in a saros will be visible from the same place on earth. Predicting solar eclipses, therefore, requires considerably more ingenuity than forecasting eclipses of the moon. If we begin a series of solar eclipses at the extreme eastern end of the ecliptic limit, we find that most of the early ones are partial and visible only in the south polar regions. At the middle of the series more total and annular eclipses visible in the middle latitudes will occur. At the end of the series, when the moon and sun meet at the western ecliptic limit, the eclipse tracks experience a latitude shift to the north polar regions. Longitude shifts also occur among successive eclipses in a saros. Suppose that the first solar eclipse in a series is visible in the central United States. One saros later the first eclipse will strike the earth's surface $\frac{1}{3}$ of a rotation, or 120° , west of its original position. The eclipse will be visible off the coast of Japan. The initial eclipse of the third saros cycle will be visible 240° west of the original, or somewhere in western Europe. But the first eclipse in the fourth cycle, occurring fifty-four years and one month later, will return to the same longitude. Thus, eclipses separated by a triple saros interval will recur at about the same place on earth.

Fig. 33 illustrates the path of totality of nine solar eclipses separated from one another by a triple saros interval. Solid marks at the west and east ends of a track indicate the points of beginning and end of totality while a dot represents the mid-eclipse point.

A partial solar eclipse would have been witnessed along a wide swath centered on the band of totality, the phase of the eclipse diminishing as we move farther away from the center of the path. Note the systematic progression northward in latitude and eastward in longitude between eclipses 1 to 4 and 7 to 9. This particular series may have been especially important because all the eclipses shown were easily visible in Mexico and Central America during the Early Classic and Classic periods of civilization. The eclipses of August 13, 128, and November 19, 290 (Julian), were total in the Maya area of Yucatán; all exceeded 50 percent partiality. It would be tempting to examine the manuscripts and carved stelae of Mesoamerica to see whether the astronomer-priests, known to have been avid eclipse watchers, actually recorded this series.

The saros is more easily recognizable relative to the other cycles listed in Table 5 for yet another reason. It is also an integral multiple of the interval between successive perigee passages (close approaches of the moon to the earth). The so-called *anomalistic month* of 27.55455 days fits exactly 239 times into the saros. This means that the corresponding eclipses in successive saroses will be of the same type: annular if the moon is distant from the earth in its orbit, total for a long duration if it is near.

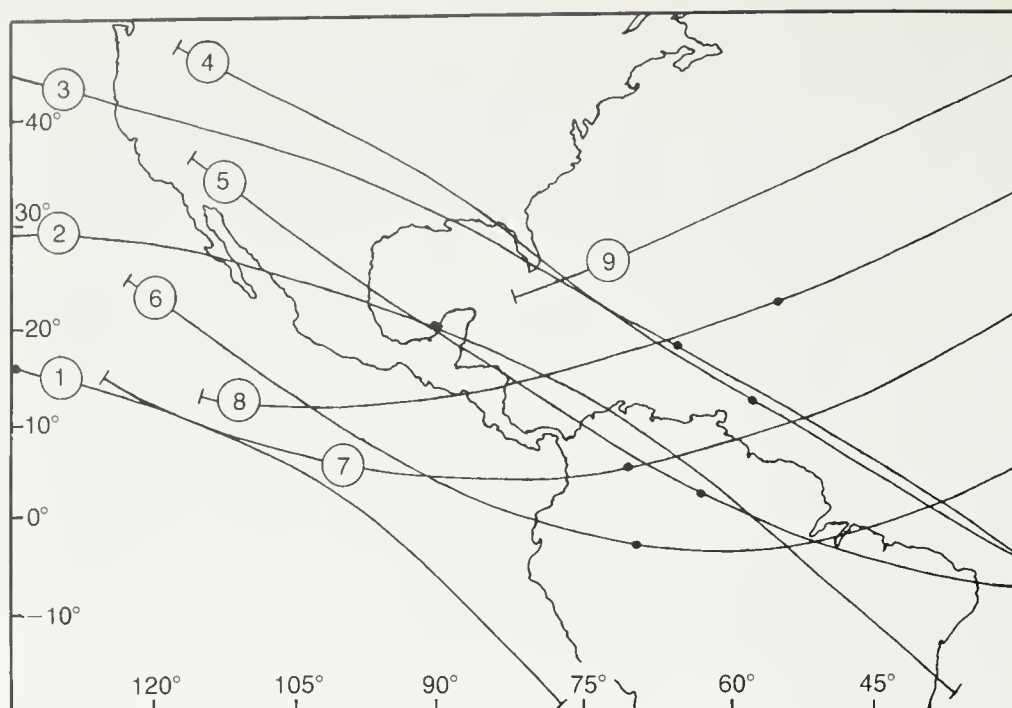
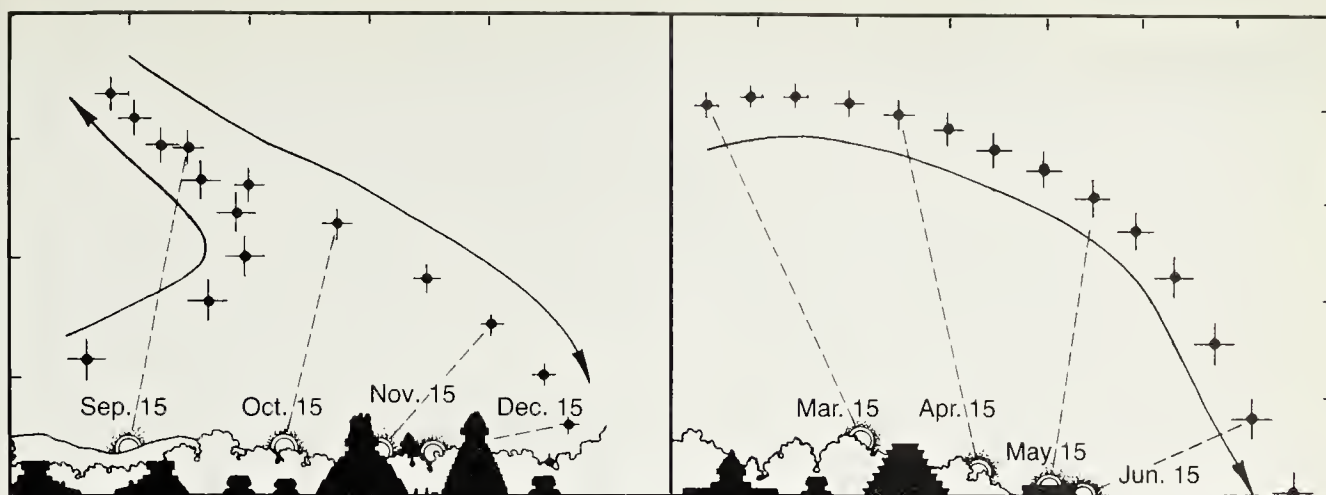


FIG. 33. A cycle of nine seasonal eclipses visible in Yucatán during the epoch of Maya florescence (lines show paths of totality): (1) July 12, 74; (2) August 13, 128; (3) September 15, 182; (4) October 17, 236; (5) November 19, 290; (6) December 21, 344; (7) January 23, 399; (8) February 24, 453; (9) March 29, 507. (Diagram by P. Dunham)

One lunar cycle well known among ancient astronomers in the Old World, and often confused with the saros and lunar nodal regression period, is the Metonic cycle, which returns the full moon to an identical date in the tropical year. A period of nineteen tropical years—(6,939.6018 days) = 235 lunar synodic months (6,939.6884 days)—does almost exactly that, missing by only two hours per cycle. The Metonic cycle is a poor eclipse cycle (255 draconic months = 6,939.1161 days) because of the slippage of about 6° of lunar motion per cycle; however, Metonic eclipses may have been accorded greater attention when they did occur because the period represents a fundamental beat between two of nature's most undisguised heavenly rhythms.

CYCLES OF THE PLANETS

Laying aside lunar considerations, let us next turn our attention to the planets and their motions. Though more complicated, the planets yield a number of recognizable cycles when followed carefully. The word *planet* means wanderer in Greek, a name which implies that the motion of these bodies across the celestial sphere is more complicated than that of the sun and moon (which the Greeks also considered to be planets). The ancients were fascinated with the periodic backward loops turned by Mars every two years. In Mesoamerica, the appearance of Venus above the horizon as morning or evening star was noted with care and precision.



Box D

According to the heliocentric theory of the solar system advanced by Copernicus during the Western Renaissance, all planets revolve about the sun, the earth being the third in order of distance from the sun. From our vantage point, Mercury and Venus, called *inferior planets* because their orbits lie between the earth and the sun, appear to oscillate back and forth relative to the sun over a short angular distance, as if attached to it by an invisible extendable cord. For the ancients they were the guardians of the sun, sometimes leading and at other times following the great luminary. By contrast, the *superior planets*, Mars, Jupiter, and Saturn, possessing orbits outside that of the earth, advance all the way around the sky and occasionally can be seen opposite the sun. The more distant planets, visible only in telescopes, were not known in ancient times.¹⁰

Since the two classes of planets behave so differently, let us illustrate the relative motion of one planet of each type, paying particular attention to the appearance of the planet to the naked eye. For the inferior planet we choose Venus (Box D), especially because of its importance among the Maya. Also, Venus is the brightest "star" in the sky and can be seen even in daylight by a careful observer. In Fig. 34 we depict Venus and the earth moving on their orbits around the sun, which is located at the center.¹¹ Suppose we align Venus (position 1), the sun, and the earth with a distant star. The time it takes Venus to complete a revolution about the sun and return to the same place on its orbit *relative to the star* is called the *sidereal revolution period*. The sidereal period of Venus is 225 days, that of the earth is $365\frac{1}{4}$ days. In modern Western astronomy, we think of these sidereal intervals as the "true" revolution periods of the planets, since they are the cycles which would be witnessed by an observer situated in a frame of reference outside the solar system, fixed relative to the stars. But for an earthbound observer the sidereal motion is not so obvious, and it is debatable whether the Mesoamericans cared about it. Anyone who watches Venus will see that planet complete its cycle relative to the sun in a period longer than 225 days. The earthbound observers travel

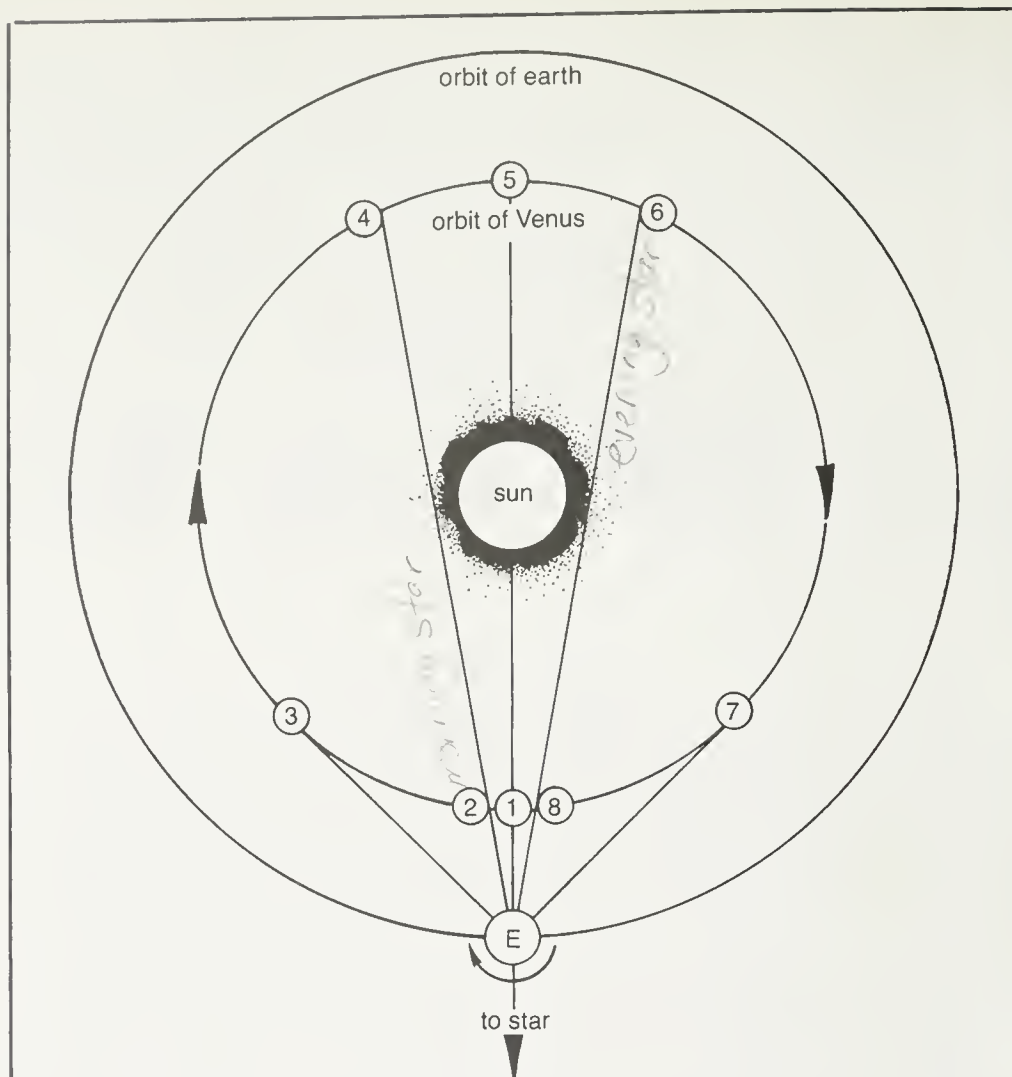


FIG. 34. The motion of Venus can be characterized by an oscillation with respect to the sun, rather like the swing of a pendulum. For simplicity in this figure, we imagine the earth, E, to be held still. (Diagram by P. Dunham)

about the sun in the same direction as Venus, though they move more slowly because they are farther from the gravitational force of the sun that binds the solar system together.

The *synodic period* of Venus is defined as the interval between successive identical configurations of that planet *relative to the sun*. Suppose we begin a synodic interval with Venus at position 1. One Venus sidereal period later the planet returns to the 6 o'clock position on the page and the earth has completed $225/365$ or about $3/5$ of its sidereal revolution. Then the earth would be approximately in the 2 o'clock position on its orbit. We must wait for 584 days, or $1\frac{3}{5}$ earth years, to elapse before the planets realign with the sun.¹² Then both will be in the 2 o'clock position. Of course they will not align with the distant star at that time. This particular synodic period will be encountered again when we decipher the Maya calendar. The Maya linked five groups of 584 days to form an important cycle of 2,920 days for the planet, probably because this period was very close to an integral num-

ber of tropical years ($8 \times 365 = 2,920$). This 2,920-day cycle may be of further significance in ancient astronomy, for it also couples the tropical year with the lunar synodic month. Thus, it functions in the same way as the Metonic cycle, though it is not as accurate:

$$99 \text{ synodic lunar months} = 2,923.53 \text{ days}$$

$$8 \text{ tropical years} = 2,921.94 \text{ days}$$

This Maya penchant for interlocking celestial periods is vividly demonstrated in their calendars, a discussion of which we defer until we become familiar with the mathematical mentality of the Mesoamericans in Chapter IV.

For simplicity, let the earth remain stationary at the position shown in Fig. 34 while Venus moves around on its orbit. Where will it appear in the sky, and how will an observer describe it at different positions in its cycle? In position 1 (*inferior conjunction*) we will not see Venus at all since it is obscured by the glare of the sun.

Given the importance that both the Maya and the Central Mexicans attached to this brief disappearance, it is conceivable that they could have detected the planet when it crossed the surface of the sun. This would happen only on those rare occasions when the line of nodes of Venus' orbit aligns with the earth-sun axis. There it could be witnessed as a black dot occupying an area equivalent to less than one ten-thousandth of 1 percent of the visible surface of the sun but as easily detectable with the naked eye as a large sunspot group. Only twenty-eight such "transits" of Venus occurred between 1000 B.C. and the conquest. Dates and other observational details are given by J. Meeus (1957).

As Venus moves ahead of the sun to position 2, it becomes a "morning star." Immediately before the sun rises over the eastern horizon, Venus appears above it for an instant, only to disappear in the morning twilight.¹³ By the next morning it has moved a little farther to the west and is visible for a longer period of time before sunrise. The first annual predawn appearance of Venus is termed its *heliacal rising*. It was probably the most important single event in Maya astronomy. A detailed discussion together with tabulated heliacal rising times of selected objects is given in Appendix C of this chapter. During this brief early-morning viewing period, Venus is also at greatest brilliancy because of its proximity to the earth. At this time it outshines every object in the sky except for the sun and moon. As Venus moves westward away from the sun, its brilliant white light diminishes slightly, but it is visible as a "morning star" for a longer interval each day. At *greatest western elongation*, position 3 in the diagram, it has moved to its maximum angular distance from the sun, 47° ,¹⁴ rising about three hours ahead of it. Then it closes on the sun and, when it reaches position 4, makes its last appearance before dawn prior to being lost in the glare of the sun again.

During the period surrounding *superior conjunction*, position 5, Venus vanishes from view for about eight weeks as it passes behind the sun. It reappears at position 6 as "evening star," visible for a short duration in the western sky after sunset. Though its apparent brightness is at a minimum because it is so distant from the earth, it is, nevertheless, one of the most prominent objects in the sky. At position 7, *great-*

est eastern elongation, Venus is visible for three hours after sunset. It then closes to last disappearance in the west after sunset, position 8; vanishes for approximately a week; and undergoes heliacal rising to complete the cycle. The Maya and later the Central Mexicans divided the motion of Venus into four intervals. They assigned an 8-day period to the disappearance at inferior conjunction, which is close to that observed today. But, peculiarly, their manuscripts recorded a disappearance interval of 90 days at superior conjunction, nearly double the true value. Furthermore, they assigned unequal values to the intervals as morning and evening star: 250 and 236 days, respectively. In fact, the true intervals are equivalent at approximately 263 days.¹⁵ Since we know that the Maya were careful and exacting timekeepers, there may have been ritualistic reasons for these changes which overrode the observations. We shall examine some of them in Chapter IV when we discuss the Venus calendar of the Maya in considerable detail.

The long-term motion of Venus can thus be described as an oscillation about the sun, the planet never straying far from its dazzling celestial superior. Little wonder that the theme of death and resurrection finds symbolic expression in the interaction of these two bodies. Among the Central Mexicans, ceremonies following the death of Tezcatlipoca (Earth Sun) were dedicated to Huitzilopochtli (Sun of the Center). The latter appears to rise from the sacrificed body of Tezcatlipoca, just as Morning Star does from the body of Quetzalcóatl (Venus) (Séjourné, 1976, p. 166).

The motion of Mars is depicted in Fig. 35. Unlike Venus, Mars is a superior planet, that is, its orbit lies outside that of the earth; consequently, it can be viewed at any angle relative to the sun. Its motion is quite contrary to the whiplike motion of Venus relative to the sun (confined in Fig. 34 within the angle 3E7). It undergoes only one disappearance per synodic revolution. The sidereal period of revolution, which begins and ends at position 1, is 687 days. The synodic period is about 780 days, but it can vary several days either way owing to the ellipticity of Mars' orbit (not exhibited in the figure).

Again holding the earth stationary in the diagram, we depict Mars at several key positions on its orbit. Though the orbit, like that of Venus, is viewed as clockwise from outside the system, we show the positions progressing in a counterclockwise sense because the earth, which travels faster on its orbit, constantly pulls ahead of slower Mars. The effect is similar to the way a driver views a moving car as he or she passes it on a highway. The passed car appears to recede into the distance relative to the highway scenery. We begin with Mars at position 1, or *opposition*. Mars then lies 180° from the sun, rises at sunset, and appears high in the midnight sky, a brilliant red object at its closest approach to earth. The distance between earth and Mars at opposition varies by about 20 percent, again because of the elliptical nature of the Martian orbit. Thus, on certain occasions, as for example in 1956, the planet is unusually close to the earth and appears very prominent in the sky. As Mars moves eastward toward position 2, it is visible as an evening star. This can be verified using the straightedge technique discussed in note 13. When it makes an angle of 90° with the sun, a superior planet is said to be at *eastern quadrature*; then it rises about six

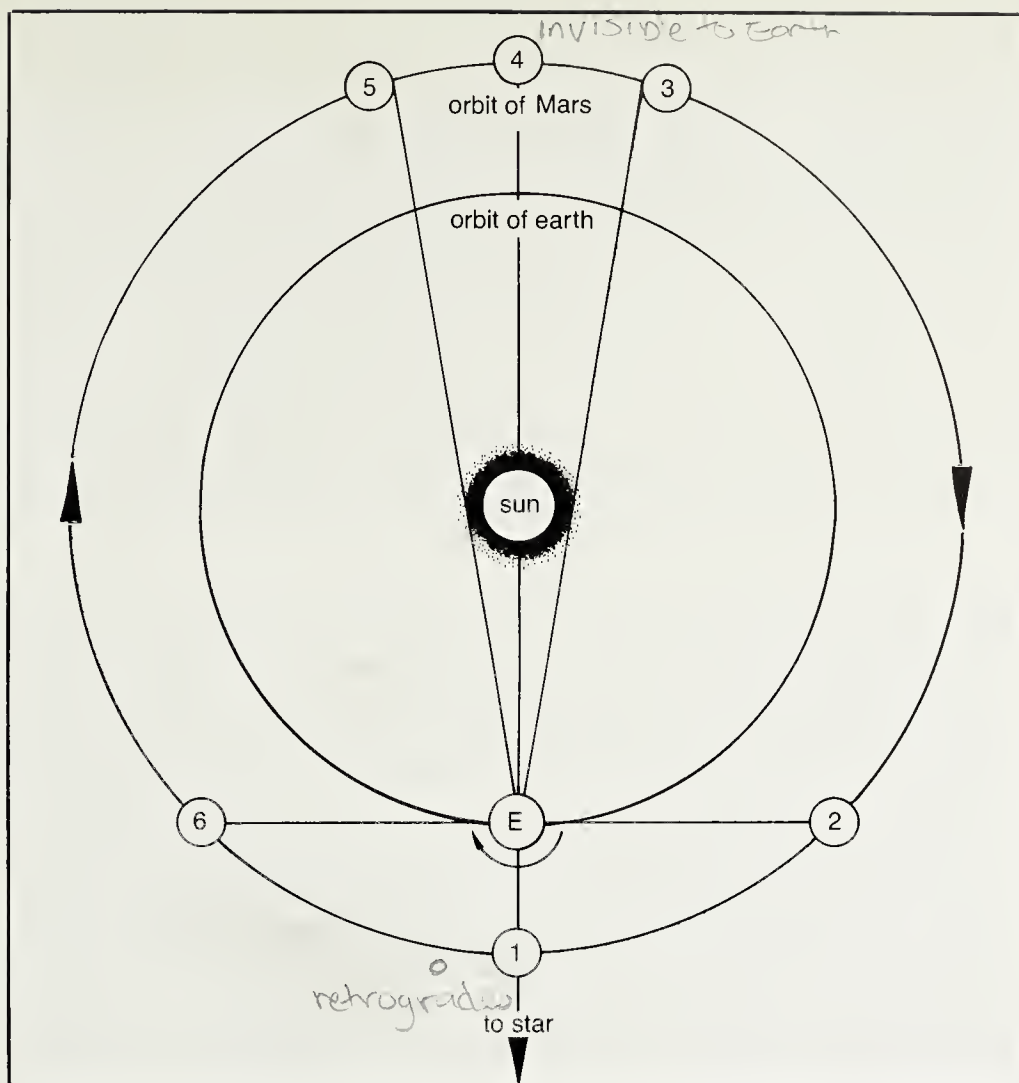


FIG. 35. The motion of Mars carries it all the way around the sky relative to the sun. Again, the earth is shown at rest. (Diagram by P. Dunham)

hours after the sun. Gradually Mars moves toward position 3 where it is last visible in the western sky after sunset. Next it begins an extended period of several weeks of invisibility to the naked eye. The red planet passes behind the sun and moves toward *conjunction*, which is marked by position 4, reappearing faintly at position 5 in the morning sky ahead of the sun (*heliacal rising*). It brightens gradually as it rises progressively earlier each day. At *western quadrature*, position 6, Mars rises at midnight. Thus, when the sun rises, Mars is already a prominent evening star situated high in the sky near the observer's celestial meridian. Finally, Mars completes its cycle by returning to opposition.

It is at the time of opposition that Mars undergoes retrograde motion relative to the stars, slowing to a stop, then turning westward among them, becoming stationary again, and, finally, resuming its normal west-to-east motion. This counter motion happens whenever the earth passes Mars in its orbit. Again the effect may be compared with that experienced by an observer in one car passing another moving in the same direction. The motion of the second car relative to the distant

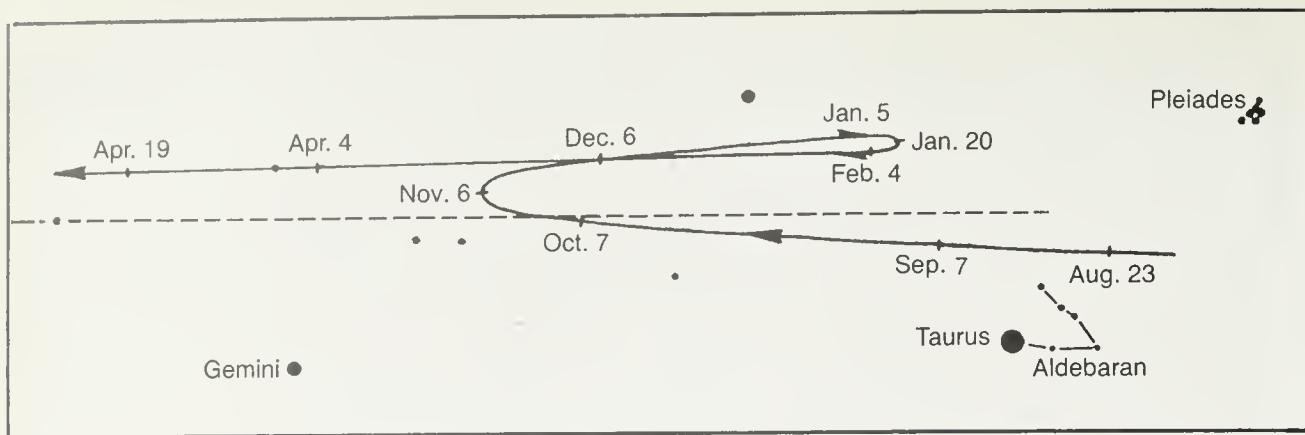


FIG. 36. The apparent path of Mars on the sky. The retrograde motion of Mars in 1975-1976 is shown. (Diagram by P. Dunham)

scenery is contrary to the direction of motion of both cars relative to the highway precisely during the time of passage.

In Fig. 36 we show a typical retrograde loop, that described by Mars during the 1975-1976 opposition. The figure traces out Mars' course relative to the background of fixed stars in the constellations of Taurus and Gemini, through which it happened to be passing at the time of opposition. As it moved eastward (from right to left in the figure) through Taurus, Mars slowed to a halt on November 6 shortly after it crossed into Gemini, then it moved backward (westward) into Taurus and headed for the Pleiades only to stop a second time on January 20. Thereafter, the planet resumed its normal west-to-east motion. To make matters even more difficult, every retrograde loop turned by Mars possesses a different size and shape. For a long time ancient European and Middle Eastern astronomers believed that retrograde motion was caused by the motion of planets on secondary orbits (epicycles) centered on primary orbits (deferents). These in turn were centered on the earth, which was fixed for eternity at the center of the universe. Even though the retrograde phenomenon occurs over the course of several weeks for each inferior planet, this peculiar shift is a startling and abrupt turn of planetary events and it is known to have been observed with great care by ancient skywatchers of the Old World.

In Table 6 we break down the movement of the naked-eye planets into the basic intervals that might have been most easily noticed by ancient astronomers. Note that the superior planets undergo only one disappearance interval per synodic period, while the inferior planets vanish both in front of and behind the sun. The mean disappearance interval has been tabulated in each case. Latitude variations and different observing conditions can produce sizable variations about the mean. For planets more distant from the sun, the time to complete a synodic revolution is observed to decrease, gradually approaching an earth year in length. For example, Saturn, the most distant naked-eye planet, scarcely moves a few degrees on its orbit around the sun before the earth has gained a lap on it.

Let us use this table and Fig. 35, substituting Jupiter for Mars, to see how the naked-eye observer might divide the movement of that

Table 6. *Important Periods (in Days) for the Naked-Eye Planets*

	<i>Sidereal Period</i>	<i>Synodic Period</i>	<i>Mean Disappearance Intervals</i>	<i>Mean Intervals as Evening/Morning Star</i>	<i>Mean Interval in Retrograde</i>
Mercury	88.0	115.9	5, 35	38*, 38*	—
Venus	224.7	583.9	8, 50	263, 263	—
Mars	687.1	780.0	120	660	75*
Jupiter	4,332.5	398.9	32	367	120
Saturn	10,758.9	378.1	25	353	140

* These intervals fluctuate widely but commonly lie within about ten days of the quoted values.

planet across the heavens. We would find that Jupiter would require about 400 days to complete a basic cycle (interval between successive heliacal risings). Since it is gone from view for about a month, it is visible on slightly fewer than 370 consecutive nights. During this time it spends about 250 days undergoing normal forward motion. For the remaining 120 days, Jupiter undergoes retrograde motion, 60 days on either side of opposition, at which time it is at greatest brilliancy.

While the determination of the synodic period of a planet from direct observation is easily accomplished, the sidereal period is much more difficult to observe directly, though it can be derived algebraically from the synodic period. There are no compelling reasons to assume the ancient Mesoamericans possessed a cosmologically based desire to know what we Westerners call the “true” revolution periods of the planets. Indeed, it is not even necessary to postulate a heliocentric solar system in order to derive these periods. Yet, since some researchers have suggested that sidereal intervals are represented in the Mesoamerican inscriptions, a brief discussion of the type of naked-eye observation required for determining sidereal cycles may be useful.

To record the sidereal period of a planet, a terrestrial observer would not simply mark the interval between successive passages of a planet by the same star (conjunction). The position of the sun relative to these events would also have to be recorded. Intervals between successive (planet-star) conjunctions which follow a conjunction of the planet with the sun could serve as a close approximation to the sidereal period of the planet. But a few complications arise in making these observations. The selection of the reference star along the ecliptic will affect the determination of the sidereal period since the apparent planetary orbit never lies precisely in the ecliptic plane. Also, the planet undergoes retrograde motion, which occasionally will delay its conjunction with the chosen star. Furthermore, if we observe a planet-star conjunction following conjunction with the sun, we have the added uncertainty of a few days in attempting to sight the emergence of the planet from the sun’s glare.

With these difficulties in mind we can, nevertheless, employ a modern set of planetary tables, for example, Tuckerman (1964), to de-

termine how accurately the sidereal periods of both inferior and superior planets could have been observed by this method.

Suppose we choose to mark the dates of planet-star conjunctions at a fixed point on the ecliptic, noting the position of the sun relative to other stars at that time. The ancients could have done this by observing which stars rose or set heliacally *on a given calendar date*. In fact, it seems logical that they would have desired to determine periods in which sets of celestial phenomena repeat themselves. Thus, they could determine the intervals between planet-star conjunctions occurring at the same time in the seasonal calendar. From such a set of observations an approximation to the sidereal period may be determined. As an example we record, below, each date that Jupiter passed longitude 0° , measured along the ecliptic, during the eleventh century:

- (1) February 3, 1003
- (2) May 27, 1014
- (3) January 13, 1015
- (4) May 2, 1026
- (5) November 2, 1026
- (6) December 9, 1026
- (7) April 13, 1038
- (8) March 27, 1050
- (9) March 11, 1062
- (10) February 22, 1074
- (11) February 4, 1086
- (12) January 14, 1098
- (13) May 1, 1109
- (14) April 13, 1121
- (15) March 26, 1133

From this record we can deduce that retrograde motion of Jupiter occurred between (4) and (6). We note also a repetition of certain dates in different calendar years: (1) and (11), (3) and (12), (4) and (13), (7) and (14), (8) and (15). The intervals between these pairs are 30,317, 30,317, 30,316, 30,316, and 30,315 days, respectively (average 30,316.2 days). Disregarding retrograde loops, the ancient astronomer easily could have discovered that these intervals also represented seven consecutive passages of Jupiter by the same star. (Count them in the table.)

Now, the 30,316.2-day interval is also an integral multiple of the synodic period of Jupiter (398.9 days), another easily observable quantity. Thus,

$$76 \times 398.9 \text{ days} = 30,316.4 \text{ days}$$

and

$$7 \times \text{sidereal period of Jupiter} = 30,316 \text{ days.}$$

It would have been a simple matter for the ancient astronomer to observe the 30,316-day and 398.9-day intervals and then, having counted Jupiter-star conjunctions between the same date in different seasonal years, to derive the sidereal period of Jupiter quite accurately. Our eleventh-century observations give the result:

Table 7. *Commensurabilities between the Sidereal and Synodic Periods of the Planets*

Planet	<i>n</i>	<i>m</i>	<i>q</i>	Error (days)
Mercury	19	25	6	2
Mercury	44	54	13	0
Mercury	145	191	46	3
Venus	5	13	8	2
Mars	15	17	32	12
Mars	22	25	47	7
Mars	37	42	79	4
Jupiter	65	6	71	5
Jupiter	76	7	83	0
Saturn	57	2	59	2

$$\frac{30,316.2}{7} = 4,330.9 \text{ days.}$$

We may compare this with 4,332.5 days, the accepted value of the sidereal period from modern observations.

The foregoing discussion can be generalized for any planet. If the sidereal period of a planet is *P*, its synodic period *S*, and the tropical year *E*, then it can be shown that

$$nS = mP = qE$$

where *n*, *m*, and *q* are integers and *m* + *n* = *q* for a superior planet, *m* − *n* = *q* for an inferior planet. Since *nS* and *qE* are observable quantities, *n* and *q* are, therefore, separately determinable. For example, for Venus:

$$\begin{aligned} nS &= qE = 2,920, \\ S &= 583.92, \end{aligned}$$

and

$$E = 365.2422.$$

We find that when *n* = 5 and *q* = 8 the equality is achieved with an error of less than two days. We tabulate similar properly proportioned (i.e., commensurable) intervals for the other planets in Table 7.

Since the sun moves 1° per day on the ecliptic, the error column gives us the difference in longitude between the sun and planet after the whole number of synodic periods tabulated. As we can see, some planetary cycles are more precise than others.

Thus, by observing the *seasonal repeatability* of conjunctions of Mars with selected stars, multiples of the sidereal period of Mars also could have been determined. For example,

(a) 17×687.1 (sidereal period)	= 11,681 days (a difference of 19 days in 32 years)
15×780 (observable average synodic period)	= 11,700 days
(b) 25×687.1	= 17,178 days (a difference of 18 days in 47 years)
22×780	= 17,160 days
(c) 42×687.1	= 28,858 days (a difference of 2 days in 79 years)
37×780	= 22,860 days

Thus, the seventeenth, twenty-fifth, and forty-second conjunctions of Mars with a given star, neglecting retrograde loops, would occur at about the same time in the tropical year. The Mars cycle depicted in example (c) is the most precise because the intervals tabulated are almost exactly equal; however, since this period is nearly eight decades in length, its deduction from repeated observations over several cycles seems less likely than cycles (a) or (b).

For Venus, the well-known 2,920-day period referred to in the Dresden Codex of the Maya turns out to fit thirteen Venus sidereal revolutions nearly perfectly:

$$\begin{aligned}
 13 \times 224.7 &= 2,921.1 \text{ days} \\
 &\quad \text{(a difference of 1.6 days in 8 years)} \\
 5 \times 583.9 &= 2,919.5 \text{ days}
 \end{aligned}$$

In this case, the number 13 could not be determined by a simple counting technique unless the astronomers realized that they should add 1 to the count every time Venus underwent retrograde motion, which for an inferior planet occurs over nearly half its cycle and hardly seems dramatic. Therefore, the direct determination of the sidereal periods of the inferior planets would have required considerably greater sophistication. The observation of long-term seasonal oppositions such as those suggested in Table 7 provided an excellent means for the ancient astronomer-priest to make predictions. Suppose, for example, that he wished to draw up an ephemeris for future planetary events. All he needed to do was go back a number of years equal to the long period and copy the phenomena for that year. If he wanted to be more precise, he could correct these events by the number of days in the error column.

We have learned that the course of a planet can be followed along the ecliptic quite easily; however, there exists abundant evidence that Mesoamerican astronomers were particularly interested in watching objects move relative to the horizon. Thus, we would like to translate our knowledge of planetary motion into the horizon system of coordinates with which we became familiar at the beginning of this chapter.

Basically, because they always lie near the ecliptic, the planets will rise and set at approximately the same position as the sun, executing one complete oscillation along the horizon in a year. But since the orbital plane of each planet is tilted slightly from the ecliptic, it can migrate to either side of the sun's path, depending upon how much its

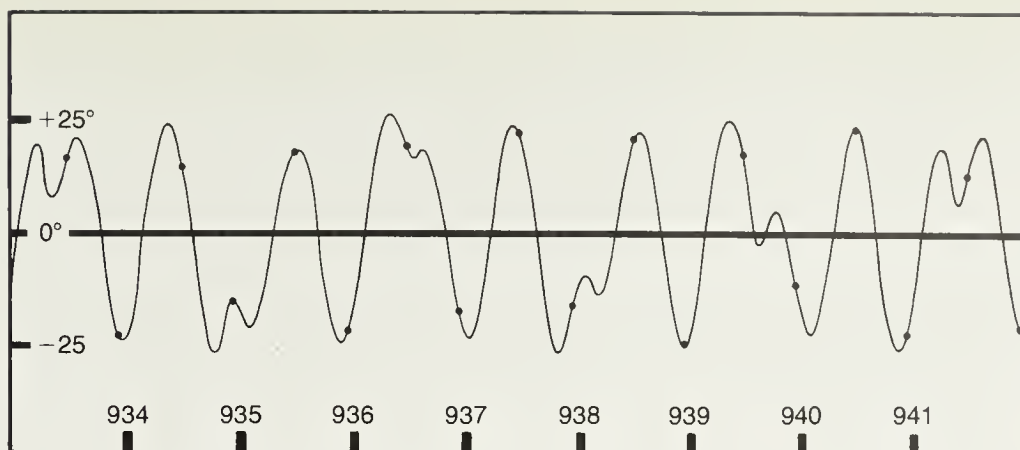


FIG. 37. The declination of Venus is charted over a decade during the Late Classic period of Maya civilization. (Diagram by P. Dunham)

orbit is inclined. Mercury and Venus have the largest orbital inclinations of the naked-eye planets, 7° and $3^\circ 24'$, respectively. Thus, if viewed from the sun, Mercury could appear as far as 7° from the plane of the ecliptic; however, as seen from the eccentric location of the earth, its position is projected slightly lower on the ecliptic. As the line of nodes formed by the planetary orbit and the ecliptic shifts through time, the extreme declination (angular distance north or south of the celestial equator) of a planet undergoes a slight change.

Fig. 37 traces the motion of Venus in declination over the course of the decade A.D. 933–942, a time when it was carefully followed in northern Yucatán. Because the deviation in azimuth is practically the same as that in declination at tropical latitudes, this curve may be regarded as an approximate representation of the position of Venus on the observer's horizon, true east and west corresponding to 0° declination. The most obvious feature of the curve is the annual motion in declination of the sun, which carries the planet with it. This is best seen when the graph is held at a distance. Successive maxima and minima are separated roughly by one-year intervals. But on closer inspection, we see that at each seasonal solar extreme, indicated by dots on the curve, the extreme northerly and southerly setting positions of Venus change noticeably. Prior to the summer solstice of A.D. 936, Venus lay far north of the ecliptic. Added to the large positive solar declination at that time, this deviation produced a maximum declination of $+27\frac{1}{2}^\circ$ for the planet. The next year Venus barely reached $+25^\circ$ declination, thus setting about $1\frac{1}{2}^\circ$ to the south of its earlier northerly standstill. From an extension of this curve over several decades, we learn that the Venus extremes were attained during April or May. But by A.D. 1000 the April event had backed up into March while the May event remained relatively fixed. The extreme declinations advanced about $\frac{1}{4}^\circ$ along the horizon during this time, making the planet a very elusive object, but Venus was not wily enough to elude the astronomers who used the Caracol observatory at Chichén Itzá to follow it, as we shall see in Chapter V. Maya inscriptions also suggest that they

were able to deduce the Venus synodic period with extreme accuracy. The astronomers seem to have been especially concerned about disappearance and reappearance of the planet for religious reasons.

It is interesting to note that the Venus motion begins to repeat itself after eight years: the shallow double maxima of A.D. 933 and 941 are nearly identical. It is a remarkable coincidence that the 584-day synodic period and the earth year of $365\frac{1}{4}$ days fit together so well. Thus, a *seasonal* recurrence of Venus events takes place every eight years. Appearance as evening star, heliacal rise, horizon extrema, and so on all fall at about the same place in our seasonal calendar every fifth Venus cycle.

Since both architectural and historical evidence suggest that the disappearance and reappearance of Venus on the horizon were extremely important, it may be worthwhile to elaborate further on how certain aspects of that planet may be foretold by viewing it at the horizon from the latitude of the Maya zone.

Fig. 38 represents a segment of the western horizon (W is the west point and north is to the right). The celestial equator (CE) is incident on the horizon at an angle of 70° (90° minus 20°) for an observer at 20° N latitude. Toward the center of the diagram two orientations of the ecliptic relative to the horizon are shown: E_1 , when the sun, having just set, is at the autumnal equinox, and E_2 , when the sun is at the vernal equinox. Suppose that on either of these occasions Venus is about to make its first appearance as evening star following blockage by the solar glare. This would happen at either of two positions assumed to lie at the same altitude: V_1 , when the planet lies along the ecliptic in configuration E_1 , and V_2 , when it lies along ecliptic E_2 . The setting motion of the planet is indicated by the dashed lines parallel to the equator. For simplicity, assume that Venus moves precisely along the ecliptic. In either case its long-term motion carries it eastward away from the sun. But it must move a greater distance along the ecliptic before becoming visible as evening star in the first case. Thus, the reappearance of Venus is delayed when the sun is at the autumnal equinox (E_1) and it is hastened when the sun is at the vernal equinox (E_2). These effects are magnified considerably in the higher latitudes where the celestial equator intersects the horizon at a smaller angle. The example demonstrates why Venus reappears neither precisely periodically nor exactly in the same location above the horizon after each disappearance behind the sun. In the first case it reappears south of the sun, in the second case above it and slightly to the north.

Should Venus reappear early in February when the ecliptic intersects the western horizon perpendicularly at sunset (position V_3 along ecliptic E_3), then the distance along the ecliptic between Venus and the sun coincides exactly with the altitude of the planet at reappearance: an early apparition of Venus is guaranteed. Thus, careful horizon observations of a planet can be of considerable value in making predictions about its movement, another fact to remember when we discuss the Caracol Venus observatory in Chapter V.

In Fig. 39 we summarize in a general way the most important events occurring along the horizon of an observer in latitude 20° N. Most of the activity occurs in zones 60° wide (shown solid and cross-

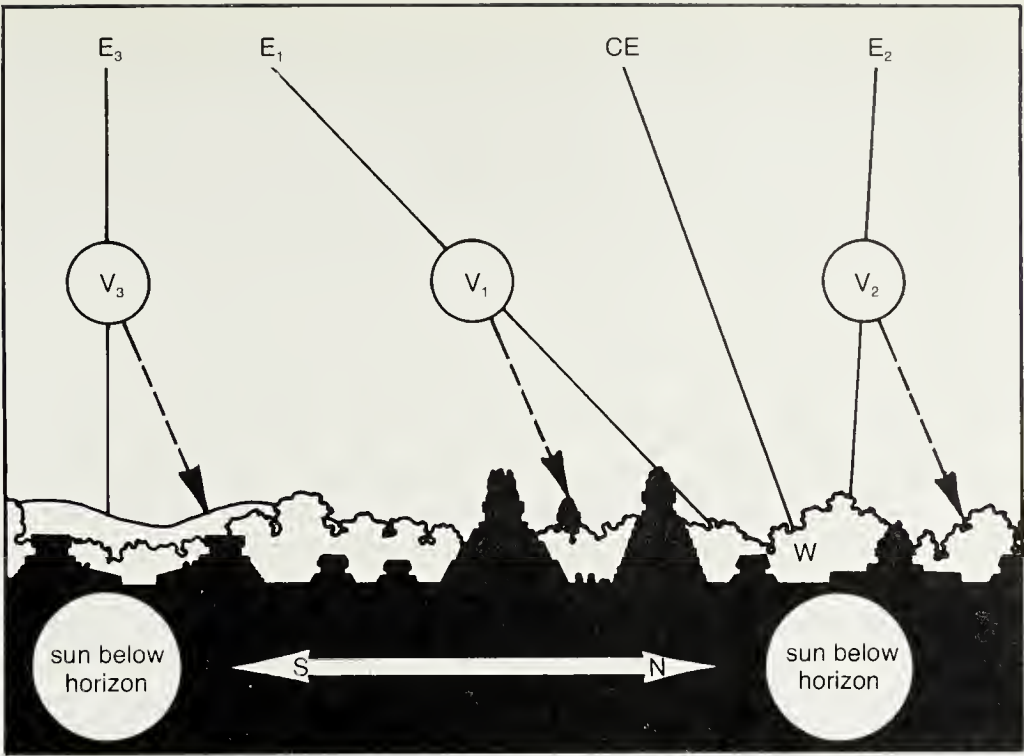


FIG. 38. Venus approaches the western horizon at sunset. The picture applies to an observer at 20° N. (Diagram by P. Dunham)

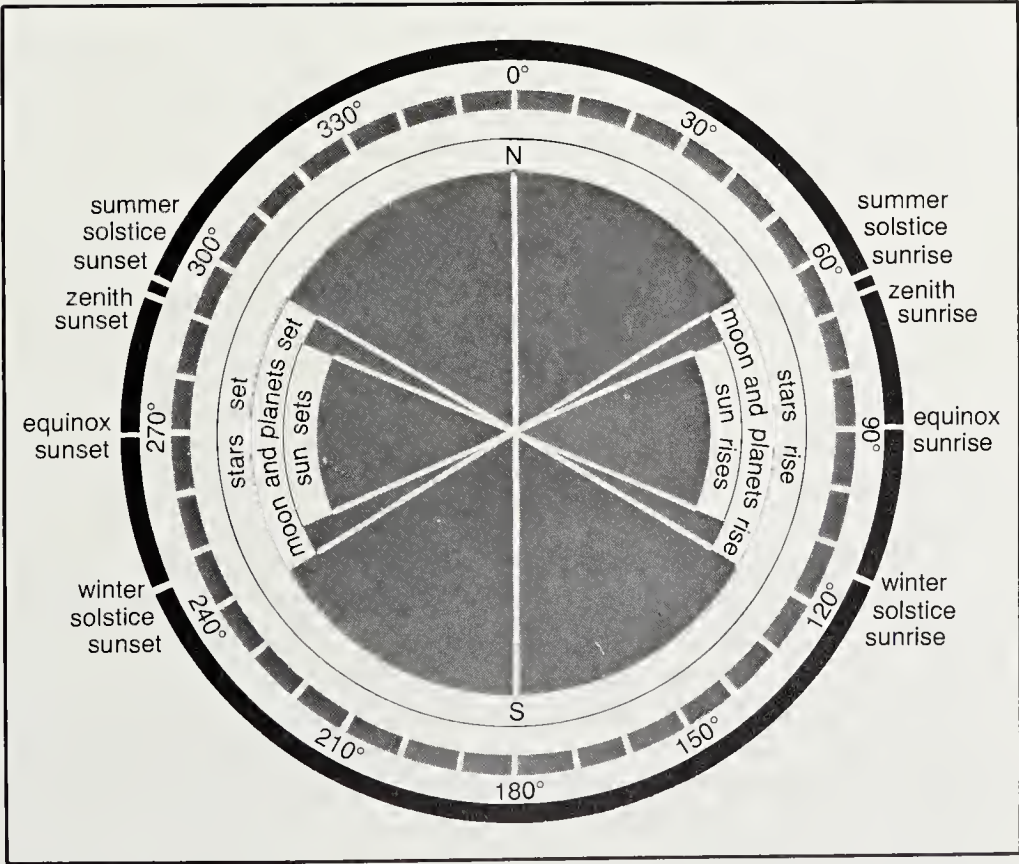


FIG. 39. Zones of the horizon where important celestial events occur for an observer at low northern latitudes. The reader looks down from the sky upon an imaginary observer at the center. (Diagram by P. Dunham)

hatched in the diagram) centered on the east and west points of the horizon where the sun, moon, and planets move. The positions of sunrise and sunset on the days when it attains the zenith are also shown. Often these are confused with the solstice points. The moon and the planets may occasionally migrate farther north or south as the figure implies. Outside these segments little else takes place. The stars, portions of the Milky Way, and an occasional comet will rise or set there.

MISCELLANEOUS OBSERVABLE PHENOMENA

Though this chapter has been intended as a useful compendium of obvious astronomical naked-eye phenomena that might have been witnessed and recorded by ancient civilizations, space does not permit us the opportunity to include discussions of all the celestial occurrences which we might anticipate. Nevertheless, a few relatively important phenomena should be mentioned and the reader directed to appropriate resource material for further consideration. While not all these celestial phenomena are documented in the historical record as having been actually observed, we might nevertheless anticipate that any attentive skywatcher would recognize them:

Comets. Bureau des Longitudes, *Annuaire pour l'an 1950*, lists 750 naked-eye aperiodic comets known to have occurred between the Mesoamerican Pre-Classic period and the conquest. The constellations in which they resided during prominence are also tabulated, together with useful descriptive references. Among the grandest of all celestial spectacles, these objects usually appear unexpectedly and remain visible for several weeks, slowly shifting their position relative to the background stars. The long nebulous tail of a comet often stretches several degrees across the sky.

Occultations. The "eclipse" of a star by a planet or, more commonly, a planet or star by the moon, though less dazzling than a solar eclipse, may have been of considerable importance, especially among people who followed zodiacal events. Two most useful references for determining the dates of ancient occultations are B. Tuckerman, *Planetary, Lunar, and Solar Positions, 601 B.C. to A.D. 1 at Five-Day and Ten-Day Intervals* and *Planetary, Lunar, and Solar Positions, A.D. 2 to A.D. 1649 at Five-Day and Ten-Day Intervals*, which list coordinates in the ecliptic system for the sun, moon, and planets.

Meteor Showers or "Shooting Stars." While it is impossible to predict the appearance of individual colossal meteors (fireballs or bolides), a complete list of intense annual showers is provided by the *Observer's Handbook*.

Supernovae. A thorough list is included in Bureau des Longitudes, *Annuaire pour l'an 1949*. More recently F. R. Stephenson has published a "Revised Catalog of Pre-Telescopic Galactic Novae and Supernovae" in the *Quarterly Journal of the Royal Astronomical Society* 17 (1976): 121-138. Supernovae are characterized by the sudden appearance of a bright star where none had been seen before. Usually at peak brilliance for only a few days, the most outstanding supernovae gradually fade

from naked-eye view within a year. The brightest example in pre-conquest times was probably the Crab Nebula Supernova of A.D. 1054, which suddenly became visible in Taurus early in July of that year. Exceeding Venus in brilliance for the first week of that month, it may even have been witnessed briefly during the daylight hours. A number of petroglyphs showing the crescent moon adjacent to a bright object recovered from the southwestern United States have been suggested as actual documentation of the event. Should it have been recorded in the Maya world, then already declining, the depiction is sure to have been far more abstract.

The Milky Way. Visible as a 10° -wide band of diffuse light passing all the way around the sky at a 62° angle to the celestial equator, the Milky Way is best viewed crossing the zenith from north to south on late summer evenings. The Maya thought of it as the umbilical cord which connected heaven and the underworld to the earth. Some think of it as a great celestial roadway. Today's Chorti Maya call it the "Camino de Santiago" after the old Spanish usage. They pay particular attention to its situation in the sky relative to the position of the sun. Andean civilizations employed the Milky Way for basic orientation (Urton, 1978a, b; 1979). The position of the Milky Way at different seasons of the year is depicted in the star maps of Fig. 21.

Meteorological Phenomena. Often neglected because modern society would tend to disregard lower atmospheric events as noncelestial, such phenomena as rainbows, the aurora borealis, solar and lunar halos, sun-dogs, tornadoes, and lightning nevertheless are mentioned in the historical record. A full discussion of the conditions under which many exotic phenomena in the realm of atmospheric optics can be found to occur is given in M. Minnaert, *The Nature of Light and Colour in the Open Air*. An excellent discussion, with photographs, of the aurora borealis is given in S.-I. Akasofu, "The Aurora Borealis," *Alaska Geographic Society* 6, no. 2 (1979).

We have seen in this chapter that nature's phenomena lie clearly in our view. It only remains for us to observe carefully and record them if we wish to comprehend the sometimes complicated interrelations among events transpiring in the heavens.

The elegant rules about eclipse prediction and the meshing of synodic and sidereal periods of the planets were derived from an inspection of the most elementary kind of data that would have been acquired by any early society possessing the interest and the means to record such phenomena once they had been observed. By studying these celestial cycles, even better by witnessing them in the heavens for ourselves, we can begin to approach the feeling of awe at the perfection and simplicity in the universe which moved Ptolemy to utter the phrase written at the head of this chapter. The data gleaned from naked-eye observation, astutely handled, yielded secrets about how the universe of the ancient astronomer would behave in the future. It remains for us to decide on the basis of cultural remains how far a given civilization proceeded in extracting the future from the past—in making predictions from observations. This is the work of the following chapters. Armed with the basic tools of practical astronomy and a data bank full of

events to watch for, we turn next to the two most revealing Meso-american cultural survivals which embody astronomical principles—the inscriptions and the architecture.

Appendix A. Glossary of Astronomical Terms of Importance in Archaeoastronomy

Almanac: table of astronomical and/or other events usually arranged in chronological order.

Altitude: angular distance measured positive upward from the horizon to the star along the star's vertical circle (CR in Fig. 16).

Annular eclipse: eclipse of the sun in which the moon is too distant to cover the solar disk. A ring of sunlight is visible around the moon at totality.

Anomalistic month: interval between successive passages of the moon by its perigee point (point nearest the earth); 27.55455 days.

Astronomical horizon (NESW in Fig. 16): circle centered on the observer and tangent to the surface of the earth at that point.

Azimuth: angular distance measured from the north point to the base of the star's vertical circle along the horizon in an easterly direction (NESAWC in Fig. 16).

Cardinal points of the horizon: in Fig. 18, N represents the *north point* of the horizon. It is defined by the intersection of an arc drawn from P perpendicular to the horizon. Once the north point has been defined, we may locate the *south point*, S, 180° opposite N on the horizon, and the *east and west points*, E and W, midway between. These are called the cardinal points of the astronomical horizon.

Celestial equator: circle XWBE in Fig. 18, which is the prolongation of the earth's equator, or *plane of rotation*, onto the celestial sphere. This great circle will be 90° distant from the celestial poles (P and P') at all points. Just as the horizon was the fundamental reference circle in the horizon system, so, too, is the celestial equator the fundamental reference circle in the equatorial system.

Celestial meridian of the observer: great circle passing through the celestial poles and the zenith (NPZS in Figs. 16 and 18).

Celestial poles: extension of the poles of rotation of the earth (CG in Fig. 17) onto the celestial sphere. Since the celestial sphere is arbitrarily large, we must imagine that the entire earth is shrunk to a point at O in order to perform this operation. For a northern observer, P is the north celestial pole in Fig. 18.

Commensurable: property that a quantity can be related to another quantity by a ratio of two small whole numbers; for example, because 5 Venus years of 584 days equals 8 earth years of 365 days, we say that the two periods are commensurable in the ratio of 5 to 8.

Conjunction: configuration of a celestial body when it lies at (or close to) the same position as another.

Declination (δ): angular distance measured from the equator to a star along the star's hour circle. It is designated as positive to the north of the equator, negative to the south, and is measured in degrees.

Draconic month: interval between successive passages of the moon by a given node of its orbit; 27.21222 days.

Eclipse year: interval between successive passages of the sun by the same node of the lunar orbit; 346.5 days. An “eclipse season” is said to occur during the extended period of passage.

Ecliptic: extension onto the celestial sphere of the earth’s *plane of revolution* about the sun. A segment of it is also shown in Fig. 18 as a great circle making an angle of $23\frac{1}{2}^\circ$ with the celestial equator. As far as terrestrial observers are concerned, this circle traces out the *annual motion of the sun on the sky* relative to the background of distant stars.

Ecliptic limit (lunar or solar): zone about the node within which a lunar or solar eclipse may take place.

Elongation: angular distance between a planet or the moon and the sun.

Ephemeris: table that lists the position of a celestial body at different times.

Equation of time: difference between apparent and mean solar time. The former is related to the observed position of the sun in the sky while the latter refers to a “mean sun” that moves uniformly on the celestial equator throughout the year. See Table 13.

Equinox: point on the celestial sphere at which the sun crosses the celestial equator. The *vernal equinox*, V in Fig. 18, is the point of intersection of the ecliptic and the celestial equator where the sun passes from the southern to the northern hemisphere. The autumnal equinox is the opposing intersection point (not shown in Fig. 18) where the sun passes from north to south. The equinox dates are March 21 and September 20, approximately.

Heliacal rising: first rising of a star after its invisibility due to conjunction with the sun.

Heliacal setting: last setting of a star before its invisibility due to conjunction with the sun. See Table 10.

Hour circles (e.g., PRBP’ and PNXP’ in Fig. 18): great circles passing through the celestial poles. They bear the same relation to the celestial equator as do vertical circles to the horizon.

Inferior conjunction: configuration of a planet in which it is obscured by passage in front of the sun.

Meridian: great circle that passes through the zenith and the north and south celestial poles.

Metonic cycle: that period (6,939.6 days or 19 years) which returns the full moon to the same date in the calendar year.

Nadir: see *Zenith*.

Node: the point(s) of the intersection of the orbit of a body with that of another or of a plane. The ascending and descending nodes of the lunar orbit refer to the points of intersection of the orbit with the ecliptic where the moon crosses the ecliptic passing to the north and to the south respectively.

Nutation: “nodding” or short-term motion of the earth’s axis superposed on precession.

Occultation: eclipse of a star or planet by the moon or another planet.

Opposition: configuration of a body when it is opposite the sun, that is, at elongation = 180° .

Penumbra: portion of the shadow from which part of a light source is occulted by a body.

Penumbral eclipse: lunar eclipse in which the moon passes through the penumbra and not the umbra of the earth's shadow.

Precession: slow conical motion of the earth's axis of rotation about the poles of the ecliptic resulting in a motion of the celestial poles among the stars in a cycle of approximately 26,000 years.

Quadrature: configuration of a planet when its elongation is 90° .

Regression of nodes: westward (backward) movement of the nodes (of the lunar orbit) along the ecliptic, one cycle being completed in 18.61 years.

Retrograde motion: apparent westward motion of a planet on the sky relative to the stars.

Right ascension (α): angular distance measured from the vernal equinox to the star's hour circle along the celestial equator in an easterly direction (VB in Fig. 18). Because this direction lies along the equator and we measure the passage of time by the rotation of the earth, the right ascension coordinate is usually expressed in hours and minutes of time instead of angular measure. The celestial equator is divided into twenty-four hours instead of 360° ; therefore, one hour of time measure is equivalent to 15° of angle measure.

Saros cycle: cycle of similar eclipses that recurs after a period of about 18.03 years (6,585.32 days).

Sidereal period: interval between successive passages of a body by a given star; for the moon, 27.32166 days.

Summer solstice: point on the celestial sphere where the sun reaches its greatest distance north of the celestial equator; about June 21.

Superior conjunction: configuration of a planet in which it is obscured by passage behind the sun.

Synodic period: interval between successive configurations of a body relative to the sun. The synodic lunar month (29.53059 days) is the month of the phases.

Syzygy: configuration of the moon when its elongation is 0° (new moon) or 180° (full moon).

Tropical year: period of revolution of the earth about the sun (or, as we see it, of the sun about the earth) with respect to the vernal equinox; 365.24220 days.

Tropic of Cancer: parallel of latitude $23\frac{1}{2}^\circ$ N.

Tropic of Capricorn: parallel of latitude $23\frac{1}{2}^\circ$ S.

Umbra: central, completely dark part of a shadow.

Vertical circles: great circles passing through the zenith and nadir, perpendicular to the horizon. ZS, ZC, and ZW each depict quarters of vertical circles in Fig. 16.

Winter solstice: point on the celestial sphere where the sun reaches its greatest distance south of the celestial equator; about December 20.

Zenith: Z, of the observer, O, the point directly overhead (opposite the direction of a plumb line in Fig. 16). The *nadir* (not shown in Fig. 16) is the point underfoot, opposite the zenith.

Rise-set phenomena were extremely important to Native American astronomers, but the discussion of horizon events in Chapter III has been quite simple and idealized. Here we consider a number of phenomena which, unfortunately, complicate the determination of precisely where a celestial body will appear or disappear on the horizon. These are considerations which must not be overlooked by field workers, especially if they are determining astronomical orientations in order to calculate precisely where a particular horizon event took place in the past.

A slight change in the rise-set azimuth of an astronomical body may be occasioned by:

1. Alteration of the equatorial coordinates of the body owing to the precession of the equinoxes
2. Refraction of light in the earth's atmosphere
3. Absorption of light by the earth's atmosphere
4. Deviation of the skyline from the astronomical horizon

PRECESSION

The movement of the earth's axis is like that of a wobbling top. Though the physical explanation is not important in the present context, one consequence of this wobbling motion is that the celestial poles and the celestial equator migrate among the stars. Since the celestial equator also moves relative to the ecliptic, the vernal equinox point will shift among the stars from one constellation of the zodiac to the next. We wonder whether Mesoamerican astronomers might have detected this motion. Though we have no solid evidence on this question, we are at least aware that the Maya utilized a zodiac consisting of a band of constellations running along the ecliptic. The motion of the vernal equinox (called precession from the Latin *praecessio*, or "going forward") takes place in a westerly direction along the ecliptic amounting to about 50 seconds of arc per year. The precessional motion VV' for 100 years (highly exaggerated) is shown in Fig. 40, with the long-term motion of both the north celestial pole and the vernal equinox among the constellations shown in the insets. The present position of the north celestial pole happens to coincide (within $1/2^\circ$) with Polaris, our present pole star, but this has not always been the case. In the epoch between 3000 and 2000 B.C., Thuban, a faint star in the tail of Draco the Dragon, was a better approximation to a pole star.

If the stars move relative to the poles and equinoxes, then their equatorial coordinates must change with time. Suppose, in Fig. 40, that the equatorial coordinates of star R in the year 1900 were VB and BR, respectively. By the year 2000 the coordinates have become $V'B'$ and $B'R$. For the case depicted in the figure, both the right ascension and the declination of R have increased.

We see from the equation in note 4 of this chapter that a change in

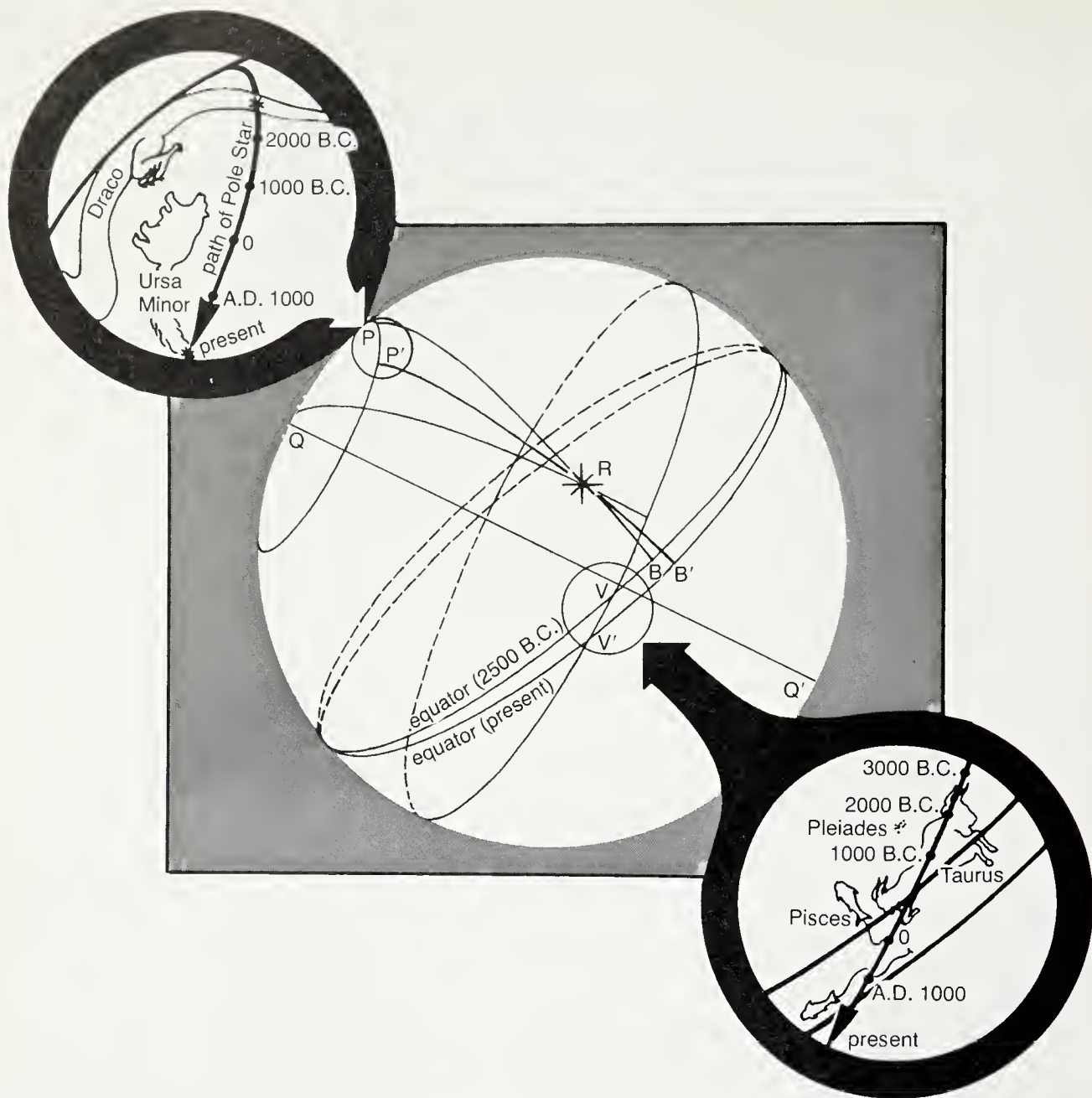


FIG. 40. The 26,000-year cycle of the precession of the equinoxes results in a motion of the celestial poles and the equinoxes among the stars that is detectable in a human lifetime. One consequence of this phenomenon of concern to the archaeoastronomer is the change of equatorial coordinates and thus the rise-set points of a star. Each mark on the scales in the enlargement of the polar region (*above left*) and of the equatorial region (*below right*) represents 1,000 years of movement. (Diagram by P. Dunham)

declination produces a change in the rising and setting azimuth of the body. Though the computed alterations in declination owing to precession are scarcely perceptible in a human lifetime, over the course of hundreds of years they may amount to several degrees. When investigating the possible astronomical alignment of ancient structures, we must utilize time-dependent tables of declination. Knowing the ap-

proximate date of erection of a structure from archaeological methods, we can supply the declinations of possible related astronomical objects for that time in order to determine whether the structure could have been oriented astronomically. Turning the problem around, we might also attempt to determine the date of construction of a building astronomically by finding when it was aligned with a particular object of known importance. Archaeological dating techniques, however, are usually far more accurate.

While the north celestial pole traces a large circular path among the stars, the vernal equinox traverses an even larger circle along the ecliptic. It completes one of the longest celestial cycles the ancients could detect—a 26,000-year circuit through the twelve constellations of the Western zodiac which straddle the ecliptic. Today, when the first day of spring arrives, the sun is in the constellation of Pisces. By A.D. 2700 the vernal equinox will have slipped into Aquarius. As we see in the lower inset of Fig. 40, two thousand years ago the vernal equinox was in Aries; in fact it was called “the first point of Aries” among the astrologers of eastern Europe. Its present symbol, Υ , is still the sign of Aries the Ram. At the time of the old Egyptian Empire, the sun stood between the horns of Taurus the Bull on the vernal equinox, a fact which is symbolized in ancient Egyptian iconography. The vernal equinox slipped by the Pleiades shortly before 2000 B.C., entering Aries about 1800 B.C., through which it slowly moved during the development of the native civilizations of America.

Changes in rising times as well as positions can be used to detect precession of the equinoxes. The passage of the sun among the zodiacal constellations is noted annually by the observation of the heliacal rising of bright stars, a phenomenon treated in detail in Appendix C of this chapter. For example, when the sun moves out of Gemini into Cancer (today this occurs in late July), the bright stars Pollux and Castor will be visible for a short period before dawn. A month later, when the sun passes into Leo they will be visible for a much longer period before sunrise. Ancient astronomers easily could detect the long-term precessional motion by witnessing changes in the *time of year* at which the bright stars underwent heliacal rising. On the average, the heliacal rise date for a bright star shifts by about one day per calendar year per human lifetime. Through myth and legend the earliest sky-watchers transmitted their consciousness of the passage of the vernal equinox along the zodiac from constellation to constellation.

The motions of the sun, moon, and planets are not affected by the precession of the equinoxes; nevertheless, small changes occur in their rising and setting positions over long periods of time because the ecliptic and the lunar and planetary orbits also undergo slight alterations relative to the fixed stars. The angle between the ecliptic and the equator (the obliquity of the ecliptic) has been steadily decreasing since recorded history by approximately 40 seconds of arc per century. We tabulate its value at different times in the past in Table 8, using the formula for the obliquity of the equator given in Woolard and Clemence (1966, p. 280). Thus, the obliquity has decreased by nearly $1/2^\circ$ between 2000 B.C. and the present, enough to result in a sizable shift in the azimuth of sunrise and sunset over the course of the past five millennia.

Table 8. *Obliquity of the Ecliptic at Different Times in the Past*

2500 B.C.	23°58'7
2000 B.C.	23°55'6
1500 B.C.	23°52'4
1000 B.C.	23°49'0
500 B.C.	23°45'4
0	23°41'7
A.D. 500	23°38'0
A.D. 1000	23°34'1
A.D. 1500	23°30'3
Present	23°26'5

REFRACTION

If we sight a star along a considerably long path through the earth's atmosphere, for example, when it is close to the horizon, we fail to see it at the true position it would occupy in the absence of an atmosphere. The phenomenon of atmospheric refraction, illustrated in Fig. 41, causes the star to appear elevated slightly above its true position. As the starlight leaves the near vacuum of interplanetary space and enters the earth's atmosphere, its direction is altered slightly toward the direction of a perpendicular to the earth's surface at the location of an observer, O. The amount of bending of the light ray increases with increasing path length down through the atmosphere. We look out along the direction of arrival of the beam and see a star at point A at angle h' above the horizon, while the position it would occupy in the absence of an atmosphere is represented by A' at angle h above the horizon. The angle AOA', or $h' - h$, the correction due to refraction, can be measured for various circumstances. It is greatly exaggerated in the figure. By simple geometry, we can calculate what the altitude, h , of a star ought to be in the absence of an atmosphere at a particular time. From actual observations we may determine h' , the apparent altitude at that time. The difference $h' - h$ can thus be found. As expected, this small correction at high altitudes is found to increase as h decreases. We simply look through more atmosphere at lower altitudes. The correction exceeds $1/2^\circ$ (a full lunar diameter on the sky) when a star is on the horizon.

With increasing altitude the path length through the atmosphere is diminished and the refraction correction becomes less until at 30° altitude it amounts to but a few seconds of arc, quite negligible in astroarchaeological studies. The inset to Fig. 41 shows the refraction correction, $h' - h$, at sea level for altitudes ranging from 0° to 20° , the only region which need concern astroarchaeologists. For observations made well above sea level, where the atmosphere is thinner, the refraction effect will be less at all altitudes above the horizon; thus, knowledge of the elevation of the site under investigation becomes part of the data to be acquired by astroarchaeologists if they wish to determine with ac-

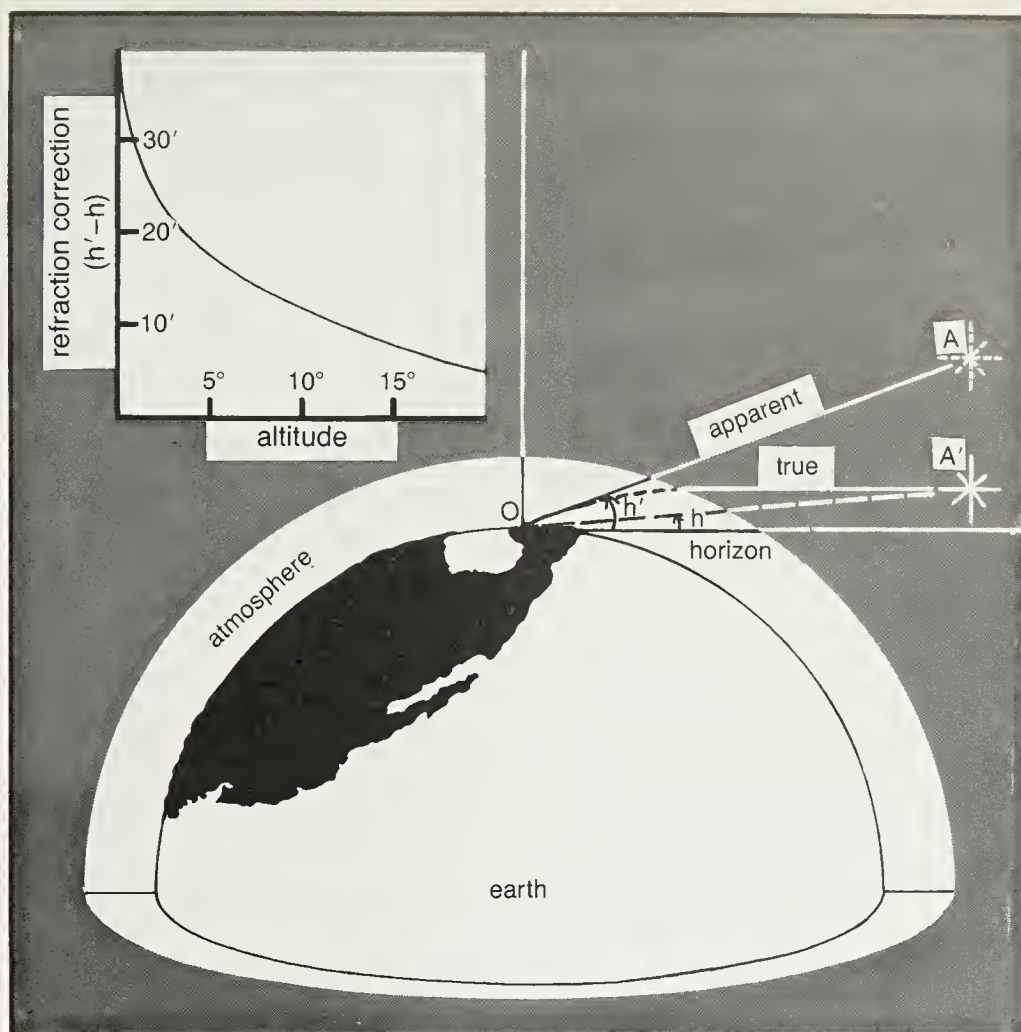


FIG. 41. Refraction boosts a star above its true position when it lies close to the horizon. *Inset*, a plot of the angle of refraction against altitude for an object above the horizon. (Diagram by P. Dunham)

curacy the place along the horizon where the particular astronomical event occurred.

What effect does atmospheric refraction have upon the rising and setting azimuths of celestial bodies? Consider an object setting along the western horizon (Fig. 42). Let the straight (dashed) line represent the setting path in the absence of an atmosphere and the curved (solid) line the path actually seen by an observer. The corresponding true and apparent positions of the star are shown at times 1, 2, and 3. Because of the elevating effect of refraction, the observed path will always lie above the true path. The observed path is curved because as the star moves closer to the horizon the refraction correction, represented by the vertical separation of the two lines, becomes more and more pronounced. A star which would have set at azimuth A_0 if there were no atmosphere is observed to set at azimuth A , some distance to the north. The reader should analyze the corresponding situation for an object rising in the east. He or she will correctly conclude that the refraction effect causes an object to appear to rise *slightly north* of its ideal rising position. Two other points are worth noting about the azimuth

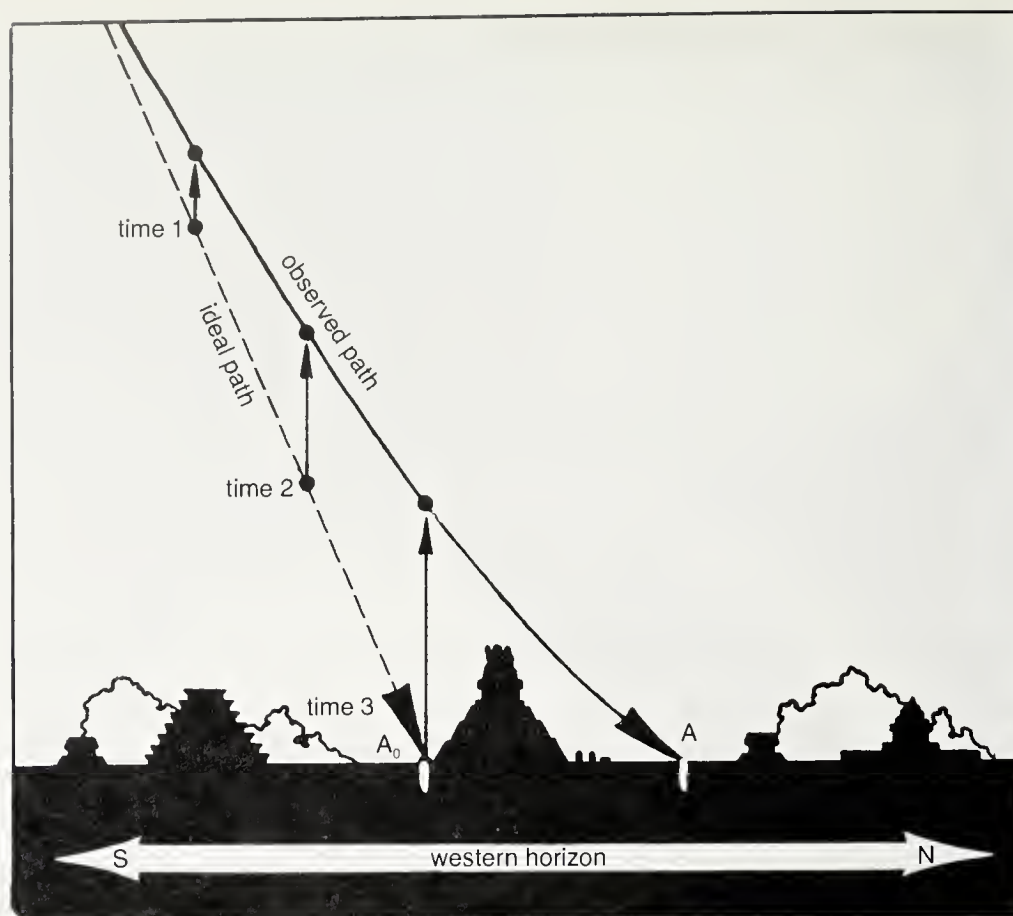


FIG. 42. The observed and ideal paths of a star as it sets in the west. (Diagram by P. Dunham)

shift due to refraction. The effect becomes more pronounced:

1. At high latitudes where the star trails make smaller angles with the horizon. In the latitude of the Valley of Mexico (about 20° N), the azimuth shift due to refraction at the east and west points of the astronomical horizon (0° altitude) is only about 12 minutes of arc; at Stonehenge (latitude 51°) it is nearly a degree, or about two lunar diameters.
2. For stars rising and setting close to the north and south points of the horizon. Here the star trails are more nearly tangent to the horizon and cannot be represented by the relatively straight line shown in Fig. 42.

EXTINCTION

Next, we consider another atmospheric effect, that of absorption (extinction) of light by the air. Since the sun and moon under favorable conditions are visible all the way to the horizon, we need be concerned only with fainter objects. But, where will a rising star which has already cleared the apparent horizon first be observable to the naked eye? This depends critically upon day-to-day conditions in the atmosphere—the amount of dust, artificial lights, distant clouds, and so forth. To-



FIG. 43. This scene of a star setting over a modern horizon shows a number of the effects discussed in the text.

day we must also consider atmospheric pollution as a factor. The most favorable daily atmospheric conditions can best be determined by long-term observations at a site. From measurements conducted in the relatively pollution free sky of rural New York State, I found that most of the very bright stars are visible down to altitudes of less than a few minutes of arc on a clear night. Hence, the resulting azimuthal shifts are negligible for most cases. If the ancients conceived of any stellar alignments in their works of architecture, they were probably concerned only with bright stars. But if stars fainter than the second magnitude were used, the extinction correction becomes important for us to consider. For example, the brightest star of the Pleiades, Alcyone (magnitude 2.9), is not visible to the unaided eye below altitudes of 3° even under the best sky conditions observed by me. For this star the azimuthal shift is about 3° at the middle latitudes.

According to Alexander Thom's investigations (1967, p. 161), the altitude above the horizon of first appearance or last disappearance of a

star is approximately equivalent to the stellar magnitude. Thus, the bright objects Venus, Jupiter, Sirius, Canopus, and Arcturus (zero magnitude or less) are visible all the way to the astronomical horizon. Castor and Pollux (first magnitude) cannot be seen below 1° of altitude, and the second-magnitude stars of the Great Dipper disappear about 2° from the horizon. As is the case for refraction, the azimuthal shift is greater in the higher latitudes.

The photograph of the setting stars in Fig. 43, taken at a middle northern latitude, demonstrates both atmospheric refraction and extinction. Refraction causes the star trails to bend slightly to the north (right) as the stars set. At the same time the stars become progressively fainter as they approach the horizon, the fainter ones disappearing from view before they touch the landscape. The lights from a shopping center in the background add an additional constraint for modern sky-watchers.

VARIATIONS IN THE SKYLINE

Ideally, we think of the rising and setting positions of an object as the points at which it crosses the astronomical horizon, a great circle at all points 90° from the observer's zenith. While this condition may be very nearly duplicated at sea, it is not the case in general. Distant mountains and valleys combine to form an undulating line which can deviate from the astronomical horizon by many degrees in places. The horizon at some of the archaeological sites in the rough terrain of Central Mexico is especially irregular.

Consider a hypothetical mountain on a segment of the eastern horizon (Fig. 44). A bright star which would rise at A_0 on the astronomical horizon actually makes its first appearance from behind the slope of the mountain at azimuth A . The astroarchaeologist, wishing to duplicate conditions as the ancients saw them, must calculate a correction, $A - A_0$, at important points along the local horizon. Thus, in determining astronomical orientations, measurements must be made of the local elevations and depressions along the horizon at a given site. In general, elevations above the astronomical horizon move the rising and setting azimuths to the south, while depressions produce an opposite shift. Again, the effect is magnified with increasing latitude and proximity to the north and south points of the horizon. We note also that the effect produced by a horizon elevation is opposite that produced by refraction. Often these two troublesome effects can cancel each other out.

All the aforementioned complications are taken into account in Table 9, which lists the rise-set positions of prominent celestial bodies as they would actually be viewed by an observer at latitude 21° N, representative of both the Valley of Mexico and northern Yucatán where the high cultures of the Americas flourished. The vertical columns give the calculated azimuths at epochs separated by five hundred years. Any differences among these columns for a given body may be attributed to precession, an effect which varies greatly with position in the equatorial system of coordinates. Contrast the 3° azimuthal shift of

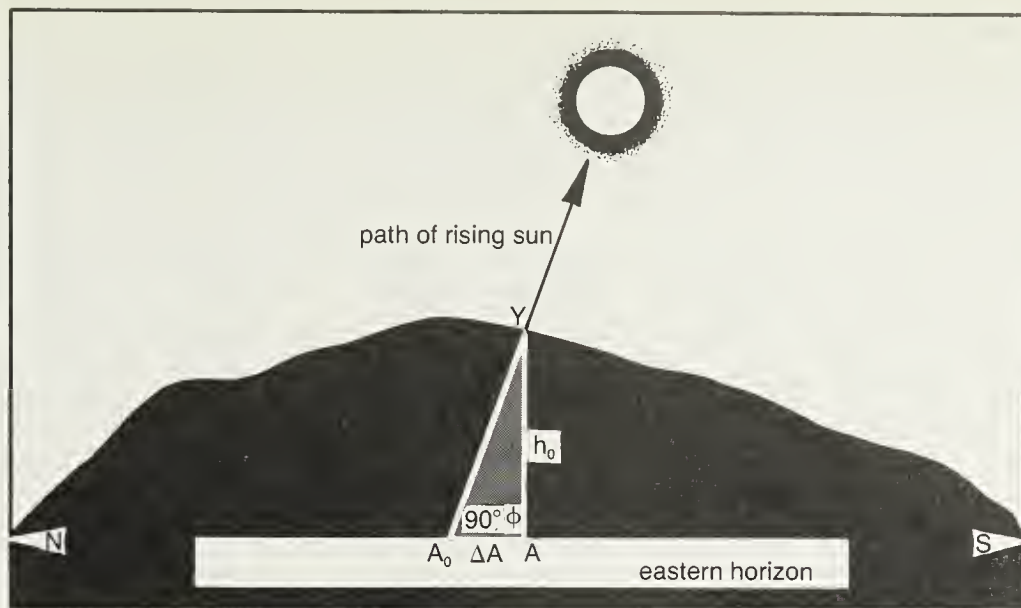


FIG. 44. Peaks and valleys along the horizon influence the determination of the azimuth at which we will first see a celestial body. (Diagram by P. Dunham)

the Pleiades with the 1° shift occurring for Pollux between 1500 and 1000 B.C. Horizon effects are apparent if we compare the data applicable for a flat horizon of 0° elevation with that which has been calculated for a horizon at altitude 3° . The sun and moon positions are determined for first and last gleam, that is, when the upper limb of either body is visible for an instant above the apparent horizon. Note how little these positions vary with time. Because the moon and sun are much closer than the other objects listed in the table, special parallax corrections also need to be made. These are discussed in detail elsewhere (see the references at the end of the chapter). Planetary positions vary irregularly by up to $1/2^\circ$ within the tabulated time intervals; therefore, they too have been omitted from the table.

Appendix C. Heliacal Rise and Set Phenomena

The annual reappearance of a bright star in the predawn sky is termed its *heliacal rising* (after *helios*, the Greek word for the sun).¹⁶ Such a visual event constitutes another manifestation of nature's calendar. Accordingly, it was duly recorded by ancient astronomers in order to fix important civil, religious, and agricultural dates in the year. As we have seen, there is considerable historical evidence that the heliacal rising of the Pleiades was observed among many ancient civilizations. Their prominence and proximity to the ecliptic were likely contributing factors.

Fig. 45 will help us to understand the circumstances involving the annual disappearance and reappearance of the stars. Here we track the sun among the stars in the vicinity of the Pleiades, showing the horizon of an observer situated in latitude 20° N on various dates. Broda (1979b) has recently suggested that the appearance and disappearance

Table 9. *Rise-Set Azimuths at Latitude 21° N*

<i>Object</i>	<i>1500 B.C.</i>		<i>1000 B.C.</i>		<i>500 B.C.</i>	
	<i>Rise</i>	<i>Set</i>	<i>Rise</i>	<i>Set</i>	<i>Rise</i>	<i>Set</i>
Horizon Altitude 0°						
Sun at summer solstice	63°59'	296°01'	64°02'	295°58'	64°06'	295°54'
Sun at winter solstice	115 21	244 39	115 18	244 42	115 14	244 46
Sun at zenith passage	67 12	292 48	67 12	292 48	67 12	292 48
Moon at north max.	58 46	301 14	58 49	301 11	58 53	301 07
Moon at south max.	121 24	238 36	121 21	238 39	121 17	238 43
Achernar	----- Does not rise or set -----					
Aldebaran	86 25	273 35	83 42	276 18	81 09	278 51
Alpha Centauri	137 06	222 54	140 09	219 51	143 14	216 46
Alpha Crucis	138 14	221 46	141 04	218 56	144 05	215 55
Polaris	----- Does not rise or set -----					
Altair	82 49	277 11	83 25	276 35	83 42	276 18
Antares	102 55	257 05	105 44	254 16	108 25	251 35
Areturus	46 31	313 29	50 00	310 00	53 25	306 35
Beta Centauri	134 46	225 14	137 53	222 07	141 06	218 54
Beta Crucis	134 05	225 55	136 56	223 04	139 57	220 03
Betelgeuse	90 22	269 38	88 16	271 44	86 26	273 34
Canopus	149 35	210 25	148 52	211 08	148 20	211 40
Capella	52 54	307 06	50 07	309 53	47 30	312 30
Castor	56 52	303 08	55 24	304 36	54 19	305 41
Deneb	49 41	310 19	48 58	311 02	48 02	311 58
Epsilon Orionis*	100 39	259 21	98 29	261 31	96 33	263 27
Fomalhaut	137 11	222 49	135 55	224 05	134 15	225 45
Pleiades	81 12	278 48	78 14	281 46	75 23	284 37
Pollux	59 43	300 17	58 30	301 30	57 39	302 21
Procyon	82 26	277 34	81 41	278 19	81 14	278 46
Regulus	64 19	295 41	65 12	294 48	66 26	293 34
Rigel	109 33	250 27	107 14	252 46	105 08	254 52
Sirius	109 18	250 42	108 14	251 46	107 26	252 34
Spica	81 13	278 47	84 04	275 56	87 00	273 50
Vega	45°44'	314°16'	46°41'	313°19'	47°25'	312°35'

* Central star of the Belt of Orion.

of this group along with the zenith sun were used to regulate festivals in the Aztec calendar. She employs the ethnohistoric record together with calculations of the type discussed in this appendix to formulate the argument.

On May 25 when the sun rises, the Pleiades are situated about 8° above the eastern horizon, having risen slightly north of the position of sunrise about half an hour before dawn. (Use the degree scale at the bottom of the diagram to verify this fact.) However, at this time they are lost in the glare of the sun; consequently, they are not detectable. By May 30 the rising sun (carrying the horizon with it in the diagram) has receded an additional 5° from the star group. When the sun rises on

0		A.D. 500		A.D. 1000		A.D. 1500	
Rise	Set	Rise	Set	Rise	Set	Rise	Set
64°10'	295°50'	64°14'	295°46'	64°19'	295°41'	64°24'	295°36'
115 10	244 50	115 06	244 54	115 02	244 58	114 58	245 02
67 12	292 48	67 12	292 48	67 12	292 48	67 12	292 48
58 57	301 03	59 02	300 58	59 06	300 54	59 10	300 50
121 13	238 47	121 08	238 52	121 04	238 56	121 00	239 00
171 42	188 18	165 40	194 20	161 09	198 51	157 16	202 44
78 48	281 12	76 41	283 19	74 50	285 10	73 17	286 43
146 22	213 38	149 30	210 30	152 38	207 22	155 43	204 17
147 15	212 45	150 36	209 24	154 10	205 50	157 59	202 01
----- Does not rise or set -----							
83 39	276 21	83 17	276 43	82 35	277 25	81 36	278 24
110 55	249 05	113 12	246 48	115 12	244 48	116 53	243 07
56 48	303 12	60 04	299 56	63 15	296 45	66 17	293 43
144 25	215 35	147 47	212 13	151 12	208 48	154 38	205 22
143 06	216 54	146 24	213 36	149 50	210 10	153 23	206 37
84 52	275 08	83 37	276 23	82 41	277 19	82 06	277 54
147 57	212 03	147 44	212 16	147 40	212 20	147 47	212 12
45 08	314 52	43 04	316 56	41 21	318 39	40 04	319 56
53 38	306 22	53 23	306 37	53 36	306 24	54 14	305 46
46 53	313 07	45 30	314 30	43 55	316 05	42 07	317 53
94 52	265 08	93 27	266 33	92 21	267 39	91 33	268 27
132 06	227 54	129 54	230 06	127 20	232 40	124 35	235 25
72 39	287 21	70 06	289 54	67 44	292 16	65 38	294 22
57 12	302 48	57 10	302 50	57 14	302 26	58 22	301 38
81 09	278 51	81 25	278 35	81 02	277 59	82 57	277 03
68 00	292 00	69 53	290 07	72 01	287 59	74 23	285 37
103 17	256 43	101 41	258 19	100 22	259 38	99 19	260 41
106 55	253 05	106 42	253 18	106 45	253 15	107 06	252 54
89 58	270 02	92 59	267 01	95 58	264 02	98 55	261 05
47°55'	312°05'	48°11'	311°49'	48°13'	311°47'	48°01'	311°59'

this date, the Pleiades are barely 12° above the horizon. At sunrise on June 4 they are 5° farther from the horizon. Observations show that the brightness of a star relative to the skyglow in the vicinity of the horizon along which it rises will determine when that star will first be observed. Stars of the first magnitude on the same horizon as the sun are found to be visible when the sun lies about 10° below the horizon; stars of the second magnitude, when it is depressed by about 14°. In the absence of morning haze, a dense clustering of third-magnitude stars like the Pleiades becomes visible when the sun is 16° or 17° below the horizon. Thus, the heliacal rise date of the Pleiades must occur about June 4. This horizon is decorated in the figure and the rising sun is

Table 9—(continued)

Object	1500 B.C.		1000 B.C.		500 B.C.	
	Rise	Set	Rise	Set	Rise	Set
Horizon Altitude 3°						
Sun at summer solstice	65°21'	294°39'	65°25'	294°35'	65°29'	294°31'
Sun at winter solstice	116 48	243 12	116 45	243 15	116 41	243 19
Sun at zenith passage	68 33	291 27	68 33	291 27	68 33	291 27
Moon at north max.	60 11	299 49	60 14	299 46	60 18	299 42
Moon at south max.	122 59	237 01	122 56	237 04	122 51	237 09
Achemar	----- Does not rise or set -----					
Aldebaran	87 42	272 18	84 59	275 01	82 26	277 34
Alpha Centauri	139 05	220 55	142 16	217 44	145 31	214 29
Alpha Crucis	140 16	219 44	143 14	216 46	146 25	213 35
Polaris	----- Does not rise or set -----					
Altair	84 06	275 54	84 42	275 18	84 59	275 01
Antares	104 15	255 45	107 05	252 55	109 48	250 12
Arcturus	48 11	311 49	51 35	308 25	54 57	305 03
Beta Centauri	136 40	223 20	139 53	220 07	143 16	216 44
Beta Crucis	135 57	224 03	138 55	221 05	142 04	217 56
Betelgeuse	91 38	268 22	89 32	270 28	87 42	272 18
Canopus	152 19	207 41	151 33	208 27	150 58	209 02
Capella	54 26	305 34	51 42	308 18	49 09	310 51
Castor	59 20	301 40	56 53	303 07	55 49	304 11
Deneb	51 17	308 43	50 35	309 25	49 40	310 20
Epsilon Orionis*	101 58	258 02	99 47	260 13	97 50	262 10
Fomalhaut	139 10	220 50	137 51	222 09	136 07	223 53
Pleiades	82 28	277 32	79 32	280 28	76 41	283 19
Pollux	61 09	298 51	59 56	300 04	59 06	300 54
Procyon	83 43	276 17	82 57	277 03	82 31	277 29
Regulus	65 42	294 18	66 34	293 26	67 47	292 13
Rigel	110 56	249 04	108 36	251 24	106 29	253 31
Sirius	110 41	249 19	109 37	250 23	108 48	251 12
Spica	82 30	277 30	85 20	274 40	88 16	271 44
Vega	47°26'	312°34'	48°21'	311°39'	49°04'	310°56'

* Central star of the Belt of Orion.

placed in the appropriate position. After this date the sun moves out of the range of the region shown in Fig. 45 and the star group becomes more prominent in the morning sky, rising progressively earlier than the sun each day. About half a year later the Pleiades will have moved halfway around the sky relative to the rising sun. At that time they take up a position on the *western* horizon as dawn twilight begins to occur. At this time they are said to undergo *heliacal setting*. For a first-magnitude star setting in the west, this event occurs when the sun is depressed about 7° below the *eastern* horizon; for second-magnitude stars the altitude of the sun must be at least minus 10°. Heliacal setting for the Pleiades occurs about November 7.

0		A.D. 500		A.D. 1000		A.D. 1500	
Rise	Set	Rise	Set	Rise	Set	Rise	Set
65°32'	294°28'	67°37'	294°23'	65°42'	294°18'	65°37'	294°23'
116 37	243 23	116 33	243 27	116 29	243 31	116 33	243 27
68 33	291 27	68 33	291 27	68 33	291 27	68 33	291 27
60 22	299 38	60 26	299 34	60 30	299 30	60 35	299 25
122 47	237 13	122 43	237 17	122 39	237 21	122 34	237 26
-----		172 52	187 08	165 52	194 08	161 01	198 59
80 05	279 55	77 59	282 01	76 08	283 52	74 35	285 25
148 51	211 09	152 15	207 45	155 42	204 18	159 13	200 47
149 48	210 12	153 27	206 33	157 26	202 34	161 52	298 08
----- Does not rise or set -----							
84 56	275 04	84 34	275 26	83 52	276 08	82 52	277 08
112 19	247 41	114 37	245 23	116 39	243 21	118 22	241 38
58 16	301 44	61 30	298 30	64 38	295 22	67 39	292 21
146 46	213 14	150 23	209 37	154 06	205 54	157 58	202 02
145 23	214 37	148 53	211 07	152 36	207 24	156 32	203 28
86 08	273 52	84 53	275 07	83 58	276 02	83 22	276 38
150 33	209 27	150 19	209 41	150 15	209 45	150 22	209 38
46 50	313 10	44 50	315 10	43 11	316 49	41 56	318 04
55 09	304 51	54 55	305 05	55 07	304 53	55 45	304 15
48 33	311 27	47 12	312 48	45 40	314 20	43 55	316 05
96 09	263 51	94 44	265 16	93 37	266 23	92 50	267 10
134 01	225 59	131 38	228 22	129 00	231 00	126 12	233 48
73 58	286 02	71 25	288 35	69 05	290 55	67 00	293 00
58 40	301 20	58 38	301 22	59 02	300 58	59 49	300 11
82 26	277 34	82 41	277 19	83 17	276 43	84 13	275 47
69 21	290 39	71 12	288 48	73 20	286 40	75 42	284 18
104 37	255 23	103 01	256 59	101 40	258 20	100 38	259 22
108 17	251 43	108 03	251 57	108 07	251 53	108 27	251 33
91 15	268 45	94 16	265 44	97 16	262 44	100 13	259 47
49°33'	310°27'	49°49'	310°11'	49°51'	310°09'	49°39'	310°21'

Now suppose that we witness a sunset on this date. Which stars will appear opposite the sun in the east? Since the Pleiades were visible low in the west at the beginning of morning twilight, they cannot yet be seen on the eastern horizon at the end of evening twilight, though the constellations of Triangulum, Aries, and Perseus, all located slightly west of the Pleiades, should appear low in the east. A few weeks later (about November 25) the Pleiades will undergo another heliacal rising, this time in the evening when they first become visible in the eastern sky after the sun has set in the west. During late fall and early winter evenings, the cluster of stars advances ever higher in the eastern sky. Finally, the sun begins to close on the Pleiades, reappear-

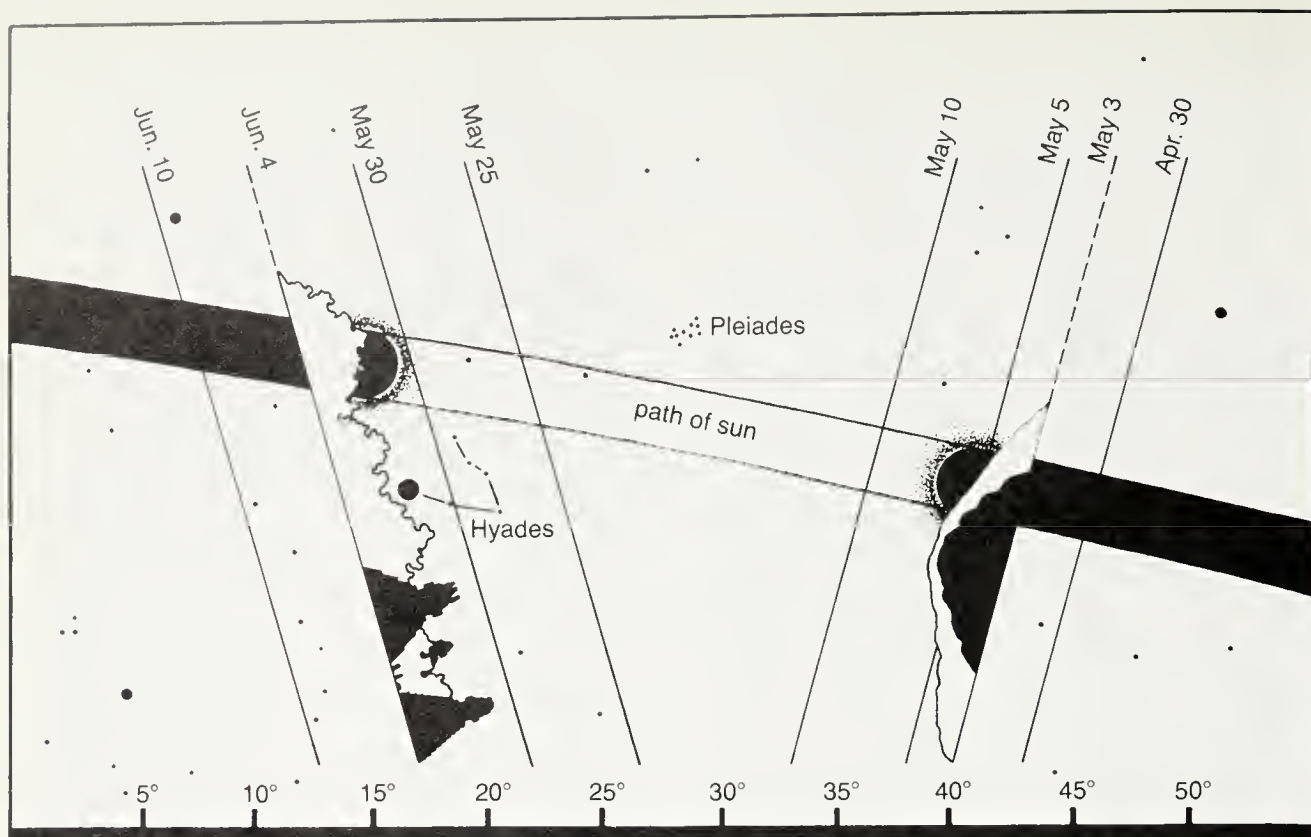


FIG. 45. Heliacal rising and setting of the Pleiades star group. Horizons for heliacal rise and set dates are dashed. Between these key dates (white zone along ecliptic) the Pleiades lie too close to the sun to be seen. (Diagram by P. Dunham)

ing at the right side of Fig. 45. On April 30, the sun has moved to within 20° of the group. By May 3, it closes to 17° and the Pleiades undergo another heliacal setting, this time being barely detectable above the western horizon at the end of twilight. Again, the horizon for this important date is embellished in the figure. A few days later, though they set after the sun, they are invisible because of its glare. The star group is then lost from view for a period of about a month, approximately May 3 to June 4; the disappearance zone is illustrated in Fig. 45 as the white segment of the sun's path along the ecliptic. On June 4 they make their celestial appointment, undergoing heliacal rise, and another astronomical cycle is resumed.

In summary, we may specify four significant dates to mark the appearance and disappearance of bright stars:

- (a) The first day on which a star is visible rising in the east before sunrise
- (b) The last day on which a star is visible setting in the west before sunset
- (c) The last day on which a star is visible rising in the east after sunset
- (d) The first day on which a star is visible setting in the west before sunrise.

For the Pleiades the dates are approximately June 4, May 3, No-

Table 10. *Heliacal Rise-Set Events for Bright Stars Observed at Latitude 21° N*

<i>Name</i>	<i>500 B.C.</i>	<i>0</i>	<i>A.D. 500</i>	<i>A.D. 1000</i>	<i>A.D. 1500</i>
Achernar	—	Jun. 23	Jun. 16	Jun. 13	Jun. 12
	—	Jan. 10	Jan. 28	Feb. 10	Feb. 20
	—	Dec. 5	Nov. 27	Nov. 23	Nov. 22
	—	Jul. 28	Aug. 15	Aug. 27	Sep. 6
Aldebaran	May 16	May 23	May 29	Jun. 4	Jun. 11
	Apr. 13	Apr. 20	Apr. 27	May 3	May 10
	Oct. 22	Oct. 29	Nov. 5	Nov. 12	Nov. 19
	Oct. 31	Nov. 7	Nov. 14	Nov. 21	Nov. 28
Alpha Centauri	Oct. 27	Nov. 4	Nov. 13	Nov. 22	Dec. 2
	Aug. 12	Aug. 16	Aug. 21	Aug. 25	Aug. 30
	Apr. 12	Apr. 20	Apr. 29	May 8	May 18
	Mar. 3	Mar. 7	Mar. 12	Mar. 17	Mar. 22
Alpha Crucis	Oct. 6	Oct. 13	Oct. 22	Oct. 31	Nov. 10
	Jul. 7	Jul. 10	Jul. 12	Jul. 13	Jul. 14
	Mar. 19	Mar. 26	Apr. 3	Apr. 13	Apr. 23
	Jan. 29	Jan. 31	Feb. 2	Feb. 4	Feb. 5
Altair	Dec. 19	Dec. 25	Dec. 31	Jan. 5	Jan. 11
	Dec. 15	Dec. 21	Dec. 27	Jan. 2	Jan. 7
	Jun. 1	Jun. 6	Jun. 12	Jun. 17	Jun. 23
	Jul. 4	Jul. 10	Jul. 15	Jul. 21	Jul. 27
Antares	Nov. 7	Nov. 15	Nov. 22	Nov. 29	Dec. 7
	Oct. 4	Oct. 11	Oct. 19	Oct. 27	Nov. 3
	Apr. 19	Apr. 27	May 4	May 11	May 18
	Apr. 30	May 7	May 14	May 21	May 28
Arcturus	Sep. 20	Sep. 28	Oct. 4	Oct. 11	Oct. 18
	Oct. 2	Oct. 8	Oct. 13	Oct. 19	Oct. 24
	Mar. 7	Mar. 14	Mar. 21	Mar. 28	Apr. 3
	Apr. 23	Apr. 28	May 3	May 8	May 13
Beta Centauri	Oct. 19	Oct. 27	Nov. 5	Nov. 15	Nov. 25
	Jul. 30	Aug. 3	Aug. 7	Aug. 12	Aug. 16
	Apr. 1	Apr. 10	Apr. 19	Apr. 28	May 9
	Feb. 21	Feb. 25	Mar. 2	Mar. 6	Mar. 11
Beta Crucis	Oct. 8	Oct. 15	Oct. 24	Nov. 1	Nov. 11
	Jul. 12	Jul. 15	Jul. 18	Jul. 21	Jul. 24
	Mar. 19	Mar. 26	Apr. 3	Apr. 12	Apr. 22
	Feb. 5	Feb. 9	Feb. 12	Feb. 15	Feb. 18
Betelgeuse	Jun. 6	Jun. 12	Jun. 17	Jun. 23	Jun. 29
	May 3	May 10	May 16	May 22	May 28
	Nov. 17	Nov. 24	Nov. 30	Dec. 6	Dec. 12
	Nov. 17	Nov. 24	Nov. 30	Dec. 6	Dec. 13
Canopus	Jul. 23	Jul. 25	Jul. 28	Jul. 30	Aug. 2
	May 5	May 7	May 10	May 12	May 15
	Jan. 12	Jan. 14	Jan. 16	Jan. 19	Jan. 21
	Nov. 13	Nov. 16	Nov. 18	Nov. 21	Nov. 23
Capella	Apr. 27	May 5	May 13	May 22	May 30
	May 1	May 9	May 18	May 26	Jun. 4

Table 10—(continued)

<i>Name</i>	<i>500 B.C.</i>	<i>0</i>	<i>A.D. 500</i>	<i>A.D. 1000</i>	<i>A.D. 1500</i>
Castor	Oct. 7	Oct. 15	Oct. 24	Nov. 2	Nov. 11
	Nov. 14	Nov. 23	Dec. 1	Dec. 10	Dec. 19
	Jun. 19	Jun. 26	Jul. 3	Jul. 10	Jul. 18
	May 23	May 30	Jun. 6	Jun. 14	Jun. 21
	Nov. 22	Nov. 30	Dec. 8	Dec. 16	Dec. 24
Deneb	Dec. 15	Dec. 23	Dec. 31	Jan. 8	Jan. 16
	Dec. 28	Jan. 1	Jan. 4	Jan. 8	Jan. 11
	Jan. 16	Jan. 20	Jan. 25	Jan. 29	Feb. 3
	Jun. 8	Jun. 11	Jun. 14	Jun. 17	Jun. 20
Orion's Belt	Aug. 6	Aug. 10	Aug. 15	Aug. 20	Aug. 24
	Jun. 13	Jun. 18	Jun. 24	Jun. 29	Jul. 4
	Apr. 22	Apr. 28	May 4	May 10	May 16
	Nov. 17	Nov. 23	Nov. 29	Dec. 5	Dec. 10
	Nov. 13	Nov. 19	Nov. 25	Dec. 1	Dec. 7
Fomalhaut	Feb. 23	Mar. 4	Mar. 12	Mar. 20	Mar. 28
	Dec. 31	Jan. 8	Jan. 17	Jan. 25	Feb. 2
	Jul. 30	Aug. 7	Aug. 15	Aug. 23	Aug. 30
	Jul. 21	Jul. 30	Aug. 7	Aug. 15	Aug. 23
Pleiades	May 7	May 13	May 19	May 24	May 29
	Mar. 29	Apr. 5	Apr. 12	Apr. 19	Apr. 26
	Oct. 2	Oct. 10	Oct. 17	Oct. 24	Nov. 1
	Oct. 22	Oct. 29	Nov. 4	Nov. 11	Nov. 18
Pollux	Jun. 20	Jun. 27	Jul. 4	Jul. 11	Jul. 19
	May 28	Jun. 5	Jun. 12	Jun. 19	Jun. 26
	Nov. 28	Dec. 6	Dec. 13	Dec. 21	Dec. 28
	Dec. 17	Dec. 25	Jan. 1	Jan. 9	Jan. 16
Procyon	Jul. 2	Jul. 8	Jul. 14	Jul. 20	Jul. 26
	May 25	May 30	Jun. 5	Jun. 11	Jun. 17
	Dec. 11	Dec. 18	Dec. 24	Dec. 30	Jan. 5
	Dec. 13	Dec. 19	Dec. 25	Jan. 1	Jan. 7
Regulus	Jul. 30	Aug. 6	Aug. 13	Aug. 19	Aug. 27
	Jun. 30	Jul. 7	Jul. 13	Jul. 20	Jul. 27
	Jan. 8	Jan. 15	Jan. 22	Jan. 29	Feb. 5
	Jan. 22	Jan. 29	Feb. 6	Feb. 13	Feb. 20
Rigel	Jun. 5	Jun. 10	Jun. 15	Jun. 20	Jun. 25
	Apr. 23	Apr. 29	May 4	May 10	May 16
	Nov. 18	Nov. 23	Nov. 28	Dec. 4	Dec. 9
	Nov. 6	Nov. 11	Nov. 17	Nov. 23	Nov. 29
Sirius	Jun. 23	Jun. 28	Jul. 3	Jul. 8	Jul. 13
	May 19	May 24	May 29	Jun. 3	Jun. 8
	Dec. 16	Dec. 21	Dec. 26	Dec. 31	Jan. 5
	Nov. 25	Nov. 30	Dec. 5	Dec. 10	Dec. 15
Spica	Sep. 22	Sep. 29	Oct. 6	Oct. 13	Oct. 20
	Aug. 20	Aug. 27	Sep. 3	Sep. 10	Sep. 17
	Mar. 4	Mar. 11	Mar. 18	Mar. 25	Apr. 1
	Mar. 17	Mar. 24	Mar. 31	Apr. 7	Apr. 14

Name	500 B.C.	0	A.D. 500	A.D. 1000	A.D. 1500
Vega	Nov. 24	Nov. 28	Dec. 2	Dec. 6	Dec. 10
	Dec. 24	Dec. 28	Dec. 31	Jan. 4	Jan. 8
	May 11	May 15	May 19	May 23	May 27
	Jul. 9	Jul. 13	Jul. 16	Jul. 20	Jul. 24

Note: These dates are given relative to the date of the vernal equinox, astronomically determined and assumed to be March 21.0. Users of Hispanic documents in Mexico prior to the Gregorian calendar reform of 1582 should be aware that the true astronomical calendar was out of step with the seasons by about ten days in the sense that the spring equinox in the European calendar in existence at the time would have been thought to begin on March 11.

vember 7, and November 25 at present. Variable sky and topographic conditions may cause these events to vary a few days either way.

Because of the precession of the equinoxes, these dates also will alter slowly over the years. For the student of American antiquity, it is important to know when the four events took place during the cultural zenith of Native American civilization. Accordingly, in Table 10 we tabulate the dates (a)–(d) for bright stars observed at latitude 21° N at 500-year intervals ranging between 500 B.C. and A.D. 1500.

Appendix D. Determining the Approximate Date of Sunrise or Sunset for a Given Azimuth

In Mesoamerica we find many instances in which structures are aligned specifically to face the sunrise or sunset on a particular date. Often prominent peaks or notches on the horizon are used to delineate a solar calendar.

Suppose that we have determined the azimuth of a particular alignment and wish to know roughly when the (center of the) sun will rise in the direction specified. For example, at Malinalco, Mexico (latitude [L] = 18°56' N), we measure the azimuth of the façade of Temple IV (the so-called Solar Temple) and find it to be A = 105°09'. We also measure a horizon altitude of 3°28' corresponding to that azimuth. To solve the problem we shall compute the declination of the sun for these circumstances and refer to a table (Table 11) of daily solar declinations.

In Fig. 44 we note that because the horizon is elevated the observed position of sunrise (point Y above azimuth A) will appear well to the south of the position of sunrise (point A₀) on the astronomical horizon. Except near the north and south points of the horizon, we see from Fig. 44 that the shift in azimuth, ΔA = A₀ – A, due to elevation is given approximately by

$$\Delta A = \frac{\Delta h}{\tan (90^{\circ}-L)},$$

Table 11. *Approximate Solar Declinations at Five-Day Intervals in the Tropical Year*

Date		Apparent Declination	Date		Apparent Declination	Date		Apparent Declination
Jan.	0	-23°08'	May	5	+16°05'	Sep.	2	+ 8°08'
	5	-22 41		10	+17 28		7	+ 6 18
	10	-22 03		15	+18 43		12	+ 4 24
	15	-21 14		20	+19 51		17	+ 2 29
	20	-20 15		25	+20 50		22	+ 0 33
	25	-19 06		30	+21 41		27	- 1 24
	30	-17 49						
			Jun.	4	+22 22	Oct.	2	- 3 20
Feb.	4	-16 24		9	+22 53		7	- 5 16
	9	-14 52		14	+23 14		12	- 7 10
	14	-13 13		19	+23 25		17	- 9 02
	19	-11 29		24	+23 26		22	-10 50
	24	- 9 41		29	+23 16		27	-12 34
Mar.	1	- 7 49	Jul.	4	+22 56	Nov.	1	-14 14
	6	- 5 54		9	+22 26		6	-15 48
	11	- 3 57		14	+21 46		11	-17 15
	16	- 1 59		19	+20 57		16	-18 35
	21	0 00		24	+20 00		21	-19 47
	26	+ 1 58		29	+18 54		26	-20 50
	31	+ 3 55						
			Aug.	3	+17 40	Dec.	1	-21 43
Apr.	5	+ 5 51		8	+16 19		6	-22 25
	10	+ 7 43		13	+14 51		11	-22 57
	15	+ 9 33		18	+13 18		16	-23 17
	20	+11 19		23	+11 39		21	-23 26
	25	+18 00		28	+ 9°56'		26	-23 23
	30	+14°35'					31	-23°08'

Note: For more accurate positions, see *American Ephemeris and Nautical Almanac* [any year]. The dates of passage of sun through zenith for a given latitude are found by equating the declination of the sun with the latitude in question. Thus, for Teotihuacán (latitude 19°41' N), the event occurs on May 19 and July 25.

wherein we assume that the angle between the rising path of the sun and the level horizon near the east and west points is approximately equal to the complement of the observer's latitude.¹⁷ Here Δh represents the elevation above the astronomical horizon. At sunset the shift occurs in the opposite direction.

To be more exact, we ought to correct for the effect of atmospheric refraction by employing Fig. 41 (inset), which tells us that about $\frac{1}{3}^\circ$ ought to be deducted from the altitude of the observed sun to obtain the altitude of the true sun when it is rising. Thus, Δh becomes $3^\circ 08'$. Substituting, we find $\Delta A = 1^\circ 04'$. Therefore, the azimuth of the true sun is found to be $A = 104^\circ 05'$. Solving the equation in note 4 of this

chapter for declination and substituting, we find $\delta = -13^{\circ}18'$ for the declination of the sun on the date which fits the orientation. Referring to Table 11, we obtain the pair of dates February 13 and October 29 to fit this solar declination.¹⁸ Thus, for the 254-day interval between October 28 and February 14 the sun rises to the north of the doorway of the façade, while between February 13 and October 29 (a 107-day interval) it rises to the south. This is tantalizingly close to the 260/105 day intervals for Copán which we discuss in Chapter IV. Furthermore, it may be significant that according to one Aztec calendric correlation New Year's day, 1 Atlcahualo, occurred on February 14.

Though the method outlined in this section is only approximate, it is, nevertheless, accurate to the day because the sun's daily movement along the horizon is rather large, except near the solstices. This simple technique may be of further use since it can be employed in the reverse sense to determine at what azimuth one can expect to view a sunrise, given a calendric date of suspected importance. We can see immediately the value of simple positional astronomy in the study of calendar and building orientation.

Appendix E. Change of Direction of the Magnetic Compass with Time in Mesoamerica

There has been much confusion among archaeoastronomy students between astronomical north and north as indicated by the magnetic compass. Since it has been hypothesized that building orientations in Mexico may reflect a knowledge of the concept of the magnetic compass (Fuson 1969; Carlson 1975), we have undertaken in this section to supply a plot (Fig. 46) showing how the magnetic declination changes with time in Mesoamerica. The source of the curve is the archaeomagnetic data of Wolfman (1973), who plots the position of the VGP, or "virtual geomagnetic pole," on the globe (such a plot is called a polar data representation curve). The north VGP is defined as one pole of a "geocentric dipole which would generate the declination and inclination values measured at a particular location" (p. 142). Field data were supplied by Wolfman to determine his polar data curve. By simple spherical geometry we reduced his results with a PDP-10 computer to yield the direction relative to astronomical north to which the magnetic compass would point for observers (a) in the center of the Yucatán peninsula (latitude = 19° N, longitude = 89° W) and (b) in Central Mexico (latitude 19.5° N, longitude 99.3° W). The curve which appears in this section is the result of averaging these two curves, which were found never to deviate by more than 2° in declination at any given time. The thickness of the line delineating the magnetic variation is a measure of the mean error derived from Wolfman's analysis of the archaeomagnetic data. Before using any of the magnetic results conclusively, the reader is cautioned to become familiar with the many vagaries of the geomagnetic field, including its annual and diurnal variations as well as local geographical anomalies. (An excellent publication on this topic is J. H. Nelson, L. Harwitz, and D. G. Knapp, *Magnetism of the Earth*.) The existence of many long-term magnetic

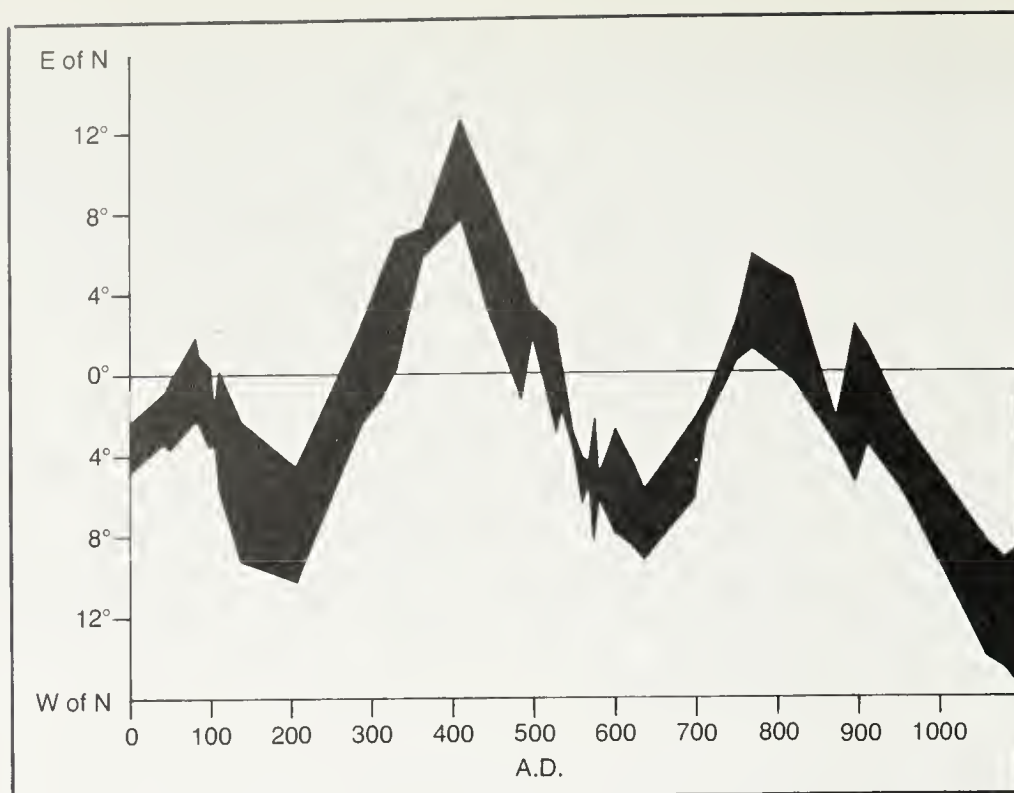


FIG. 46. The direction of the magnetic compass relative to true north in Mesoamerica as a function of time for the period during which civilization flourished there. (Diagram by P. Dunham)

variations of indeterminate origin and magnitude should serve as a warning to investigators not to rely too precisely on results obtained by simply matching building orientations with magnetic field directions in the past.

I am indebted to David Burgoyne for computing and plotting the curve.

Appendix F. Archaeoastronomy Computer Programs for a Portable Programmable Calculator

In order to aid investigators pursuing studies of building alignment and calendar, I am making available two programs written specifically for a Texas Instruments (TI-59) Programmable Calculator. The programs, written by Matthew Iatridis of the Colgate University Computer Center, are easily adaptable to most programmable calculators.

The following programs are documented: (a) an "azimuth finder" for use with a surveyor's transit (excellent for field study), allowing one to obtain immediately the correct azimuth and altitude of the sun as well as the true azimuth of any alignment, and (b) an azimuth or declination predictor for sun, stars, and moon.

The second program is particularly useful when one, having determined the azimuth of an alignment in the field, wishes to know what object might appear at a prominent point on the horizon adjacent to the alignment.

Program Description

Azimuth finder for use with surveyor's transit. Program will return the correct azimuth and altitude of the sun for any given time or place as well as the azimuth of any alignment. Program solves the following equations:

Hour angle of sun (HA) in degrees = (GMT - 12) · 15 - LONG - EOT · 15

Altitude of sun = Arcsin (Sin(LAT) · Sin(DEC) + Cos(LAT) · Cos(DEC) · Cos (HA))

Azimuth of sun = Arcsin (Sin(HA) · Cos(DEC) ÷ Cos (ALT))

Azimuth of sun = Arccos ((Sin(DEC) - Sin(LAT) · Sin(ALT)) ÷ (Cos(LAT) · Cos(ALT)))

Where

- = multiplied by
- GMT = Greenwich Mean Time
- EOT = Equation of time
- LAT = Latitude of site
- LONG = Longitude of site
- HA = Hour angle of sun
- DEC = Declination of sun
- ALT = Altitude of sun

Note: The azimuth of the sun equals the azimuth from the Arccos if the azimuth from the Arcsin is negative. If the azimuth from the Arcsin is positive, then the azimuth of the sun equals 360 minus the azimuth from the Arccos.

User Instructions

Step	Procedure	Enter	Press	Display
1	Enter the declination of the sun for the day on which the work is done; enter in the form DD.MMSS (degrees, minutes, seconds)	DD.MMSS	A	DD.dddd
2	Enter the latitude of the site	DD.MMSS	B	DD.dddd
3	Enter the longitude of the site	DD.MMSS	C	DD.dddd
4	Enter the time of the sun sighting in GMT time; use 24-hour time: GMT = EST + 5 hours = CST + 6 hours, etc.	HH.MMSS	D	HH.hhhh
5	Enter equation of time Note: Steps 1 through 5 can be done in any order; before running the program for the first time or again, clear and reset program with second E'	bmm.SS	E 0 2nd E'	MM.mmmm 0.0000
6	Running the program: after pressing second A', the azimuth of the sun is returned to the display; pressing x ≥ t will display the altitude of the sun; pressing x ≥ t again will display the azimuth again		2nd A' x ≥ t	DDD.MMSS DD.MMSS

User Instructions—(continued)

Step	Procedure	Enter	Press	Display
7	Enter azimuth of the sun as read off the transit	DD.MMSS	2nd B'	DD.dddd
8	Enter azimuth of alignment as read off the transit; now the display will hold the true azimuth of the alignment; repeat Step 8 as needed (other data need not be re-entered)	DD.MMSS	2nd C'	DDD.MMSS
9	Clear and reset before going on to next problem		0 2nd E'	0.0000

Coding Form

Step	Code	Key	Comments	Step	Code	Key	Comments
0	76	2nd Lbl	} clear to reset PGM	35	04	4	} enter AZ sun
1	10	2nd E'		36	92	INV SBR	
2	58	2nd FIX		37	76	2nd Lbl	
3	4	4		38	17	2nd B'	
4	47	2nd CMs		39	88	2nd D.MS	
5	60	2nd Deg	} enter DEC	40	42	STO	} run section
6	92	INV SBR		41	05	5	
7	76	2nd Lbl		42	92	INV SBR	
8	11	A		43	76	2nd Lbl	
9	88	2nd D.MS		44	16	2nd A'	
10	42	STO	} enter LAT	45	53	(} GMT
11	00	0		46	43	RCL	
12	92	INV SBR		47	03	3	
13	76	2nd Lbl		48	75	—	
14	12	B		49	01	1	
15	88	2nd D.MS	} enter LONG	50	02	2	} LONG
16	42	STO		51	54)	
17	01	1		52	65	×	
18	92	INV SBR		53	01	1	
19	76	2nd Lbl		54	05	5	
20	13	C	} enter GMT	55	75	—	} EOT·15/60
21	88	2nd D.MS		56	43	RCL	
22	42	STO		57	02	2	
23	02	2		58	75	—	
24	92	INV SBR		59	43	RCL	
25	76	end Lbl	} enter EOT	60	04	4	} hour angle
26	14	D		61	55	÷	
27	88	2nd D.MS		62	04	4	
28	42	STO		63	95	=	
29	03	3		64	42	STO	
30	92	INV SBR	} enter EOT	65	10	10	} LAT
31	76	2nd Lbl		66	53	(
32	15	E		67	43	RCL	
33	88	2nd D.MS		68	01	1	
34	42	STO		69	38	2nd SIN	

Coding Form—(continued)

Step	Code	Key	Comments	Step	Code	Key	Comments
70	65	×		117	75	—	
71	43	RCL		118	43	RCL	
72	00	0	DEC	119	01	01	LAT
73	38	2nd SIN		120	38	2nd SIN	
74	85	+		121	65	×	
75	43	RCL	LAT	122	43	RCL	
76	01	1		123	11	11	ALT
77	39	2nd COS		124	38	2nd SIN	
78	65	×		125	54)	
79	43	RCL	DEC	126	55	÷	
80	00	0		127	53	(
81	39	2nd COS		128	43	RCL	
82	65	×		129	01	1	LAT
83	43	RCL		130	39	2nd COS	
84	10	10	hour angle	131	65	×	
85	39	2nd COS		132	43	RCL	
86	54	)		133	11	11	ALT
87	22	INV		134	39	2nd COS	
88	38	2nd SIN		135	54)	
89	95	=		136	54)	
90	42	STO		137	22	INV	
91	11	11	ALT	138	39	2nd COS	
92	53	(		139	95	=	AZ
93	53	(		140	42	STO	sun from
94	43	RCL		141	13	13	Arcsin
95	10	10	hour angle	142	29	2nd CP	clear T reg
96	38	2nd SIN		143	43	RCL	
97	65	×		144	12	12	AZ sun (sin)
98	43	RCL		145	22	INV	
99	00	0	DEC	146	77	2nd X ≥ T	if — go To
100	39	2nd COS		147	95	=	label =
101	54	)		148	03	3	position then
102	55	÷		149	06	6	360 — AZ sun
103	43	RCL		150	00	0	(cos)
104	11	11	ALT	151	75	—	
105	39	2nd COS		152	76	2nd Lbl	
106	54	)		153	95	=	
107	22	INV		154	43	RCL	AZ sun (cos)
108	38	2nd SIN		155	13	13	
109	95	=	AZ sun	156	95	=	
110	42	STO	from	157	42	STO	correct
111	12	12	Arcsin	158	14	14	AZ sun
112	53	(		159	22	INV	
113	53	(		160	88	2nd D.MS	load AZ
114	43	RCL		161	32	X ≥ T	sun and
115	00	0	DEC	162	43	RCL	
116	38	2nd SIN		163	11	11	ALT sun

Coding Form—(continued)

Step	Code	Key	Comments	Step	Code	Key	Comments
164	22	INV		191	77	2nd X \geq T	if ≥ 0 go to
165	88	2nd D.MS		192	85	+	label +
166	32	X \geq T		193	03	3	
167	92	INV SBR	stop	194	06	6	
168	76	2nd Lbl		195	00	0	
169	18	2nd C'	enter AZ	196	44	SUM	add 360
170	88	2nd D.MS	alignment	197	15	15	-, AZ
171	85	+		198	61	GTO	
172	43	RCL		199	65	\times	
173	14	14	AZ sun completed	200	76	2nd Lbl	
174	75	-		201	75	-	subtract
175	43	RCL		202	03	3	360° from
176	05	5	AZ sun read	203	06	6	AZ
177	95	=		204	00	0	
178	42	STO		205	22	INV	
179	15	15		206	44	SUM	
180	76	2nd Lbl	get AZ alignment	207	15	15	
181	65	\times	between 0°	208	61	GTO	
182	03	3	and 360°	209	65	\times	
183	06	6		210	76	2nd Lbl	
184	00	0		211	85	+	
185	32	X \geq T		212	43	RCL	display
186	43	RCL		213	15	15	AZ alignment
187	15	15		214	22	INV	
188	77	2nd X \geq T	if ≥ 360 go to	215	88	2nd D.MS	
189	75	-	label -	216	92	INV SBR	
190	29	2nd CP				END	

Azimuth-Declination Predictor for TI-59 Calculator

Program Description

Azimuth-declination predictor for stars, sun, and moon. Program solves the following equations:

$$\text{Azimuth} = \text{Arcos} \left(\frac{(\text{Sin}(\text{DEC}) - \text{Sin}(\text{ALT}) \cdot \text{Sin}(\text{LAT}))}{(\text{Cos}(\text{ALT}) \cdot \text{Cos}(\text{LAT}))} \right)$$

$$\text{Declination} = \text{Arcsin} (\text{Cos}(\text{ALT}) \cdot \text{Cos}(\text{LAT}) \cdot \text{Cos}(\text{AZ}) + \text{Sin}(\text{ALT}) \cdot \text{Sin}(\text{LAT}))$$

Given DEC, LAT, and ALT one can find azimuth or given LAT, ALT, and AZ one can find declination.

Program corrects for refraction of atmosphere up to 10° above horizon. Sun and moon calculations are for first and last gleam. Parallax of moon is also included in lunar calculations.

Limitations: Program is recommended for use between 0° to 10° altitude for an object, but will work for altitudes larger or smaller. Note, the program changes the stored value of altitude and therefore it must be re-entered for each calculation. Caution must be used not to try to do calculations on circumpolar stars and stars that never rise; both situations may return a value which will be incorrect.

User Instructions

Step	Procedure	Enter	Press	Display
	To find azimuth:			
1	Enter declination of object in degrees, minutes, seconds	DD.MMSS	A	DD.dddd
2	Enter latitude of the site	DD.MMSS	B	DD.dddd
3	Enter altitude of object (horizon):	DD.MMSS	2nd A'	DD.dddd
4	for azimuth of the star on the west		C	DDD.MMSS
(5)	for azimuth of the same star on the east		x ≥ t	DD.MMSS
4	for azimuth of the sun, last gleam		D	DDD.MMSS
(5)	for azimuth of the sun, first gleam		x ≥ t	DD.MMSS
or				
4	for azimuth of the moon, last gleam		E	DDD.MMSS
(5)	for azimuth of the moon, first gleam		x ≥ t	DD.MMSS
	Note: Do not do repeated calculations C, D, or E without re-entering altitude, Step 3, as the program modifies it.			
	To find declination:			
1	Enter true azimuth of object in degrees, minutes, seconds	DD.MMSS	2nd B'	DD.dddd
2	Enter latitude	DD.MMSS	B	DD.dddd
3	Enter altitude:	DD.MMSS	2nd A'	DD.dddd
4	for declination of star		2nd C'	DD.MMSS
or				
4	for declination of sun		2nd D'	DD.MMSS
or				
4	for declination of moon		2nd E'	DD.MMSS

Coding Form

Step	Code	Key	Comments	Step	Code	Key	Comments
0	76	2nd Lb1	} enter DEC	9	12	B	} enter LAT
1	11	A		10	88	2nd D.MS	
2	88	2nd D.MS		11	42	STO	
3	42	STO		12	01	01	
4	00	00		13	92	INV SBR	} enter ALT
5	58	2nd FIX		14	76	2nd Lb1	
6	04	4		15	16	2nd A'	
7	92	INV SBR		16	88	2nd D.MS	
8	76	2nd Lb1		17	42	STO	

Coding Form—(continued)

Step	Code	Key	Comments	Step	Code	Key	Comments
18	02	02		65	06	6	
19	92	INV SBR		66	00	0	
20	76	2nd Lbl		67	75	—	
21	17	2nd B'		68	43	RCL	
22	88	2nd D.MS		69	04	04	
23	42	STO	enter	70	95	=	west
24	03	03	AZ	71	22	INV	convert
25	58	2nd FIX		72	88	2nd D.MS	to degrees
26	04	4		73	92	INV SBR	
27	92	INV SBR		74	76	2nd Lbl	compute
28	76	2nd Lbl	compute	75	18	2nd C'	DEC
29	13	C	AZimuth	76	71	SBR	compute
30	71	SBR	go compute	77	65	×	new ALT
31	65	×	new ALT	78	43	RCL	
32	53	(	(	79	02	02	
33	43	RCL		80	39	2nd COS	cos(ALT)
34	00	00		81	65	×	×
35	38	2nd SIN	sin(DEC)	82	43	RCL	
36	75	—	—	83	01	01	
37	43	RCL		84	39	2nd COS	cos(ALT)
38	02	02		85	65	×	×
39	38	2nd SIN	sin(ALT)	86	43	RCL	
40	65	×	×	87	03	03	
41	43	RCL		88	39	2nd COS	cos(AZ)
42	01	01		89	85	+	+
43	38	2nd SIN	sin(LAT)	90	43	RCL	
44	54	)	)	91	02	02	
45	55	÷	÷	92	38	2nd SIN	sin(ALT)
46	53	(	(	93	65	×	
47	43	RCL		94	43	RCL	
48	02	02		95	01	01	
49	39	2nd COS	cos(ALT)	96	38	2nd SIN	sin(LAT)
50	65	×	×	97	95	=	
51	43	RCL		98	22	INV	
52	01	01		99	38	2nd SIN	Arcsin
53	39	2nd COS	cos(LAT)	100	22	INV	convert to
54	54	)	)	101	88	2nd D.MS	degrees
55	95	=		102	95	=	
56	22	INV	Arccos	103	92	INV SBR	
57	39	2nd COS		104	76	2nd Lbl	subroutine
58	95	=		105	65	×	to compute
59	42	STO		106	29	2nd CP	change in
60	04	04		107	43	RCL	ALT
61	22	INV	convert	108	02	02	
62	88	2nd D.MS	to degrees	109	77	2nd x ≥ t	is ALT ≥ 0?
63	32	x ≥ t	east	110	77	2nd x ≥ t	Yes, jump
64	03	3		111	43	RCL	no, then < 0

Coding Form—(continued)

Step	Code	Key	Comments	Step	Code	Key	Comments
112	10	10	use 0 ALT	159	44	SUM	
113	44	SUM	add it	160	02	02	
114	02	02	to ALT	161	92	INV SBR	
115	92	INV SBR	return	162	76	2nd Lbl	sun AZ
116	76	2nd Lbl		163	14	D	change
117	77	2nd x \geq T		164	93	.	ALT
118	01	1		165	01	1	by
119	00	0		166	06	6	-16 minutes
120	32	x \geq T		167	88	2nd D.MS	
121	43	RCL		168	22	INV	
122	02	02		169	44	SUM	
123	22	INV		170	02	02	
124	77	2nd x \geq T	is ALT < 10?	171	61	GTO	
125	85	+	yes, jump	172	13	C	
126	92	INV SBR	no, return	173	76	2nd Lbl	moon AZ
127	76	2nd Lbl		174	15	E	change
128	85	+		175	93	.	ALT by
129	59	2nd INT		176	04	4	+41 minutes
130	85	+		177	01	1	
131	01	1		178	88	2nd D.MS	
132	00	0		179	44	SUM	
133	95	=		180	02	02	
134	42	STO		181	61	GTO	
135	05	05		182	13	C	
136	73	RCL 2nd Ind	get REF	183	76	2nd Lbl	sun DEC
137	05	05		184	19	2nd D'	change
138	69	2nd OP	add one to	185	93	.	ALT by
139	25	25	REG 05	186	01	1	-16 minutes
140	75	-		187	06	6	
141	73	RCL 2nd Ind		188	88	2nd D.MS	
142	05	05		189	22	INV	
143	95	=		190	44	SUM	
144	42	STO		191	02	02	
145	06	06		192	61	GTO	
146	43	RCL		193	18	2nd C'	
147	02	02		194	76	2nd Lbl	moon DEC
148	22	INV		195	10	2nd E'	change
149	59	2nd INT		196	93	.	ALT by
150	65	x		197	04	4	41 minutes
151	43	RCL		198	01	1	
152	06	06	patch	199	88	2nd D.MS	
153	85	+		200	44	SUM	
154	69	2nd OP		201	02	02	
155	35	35	REG 05	202	61	GTO	
156	73	RCL 2nd Ind		203	18	2nd C'	
157	05	05				END	
158	95	=					

(See note on following page)

Note: The following data (REF) must be loaded into data registers 10–20:

- 10 ALT correction for 0° alt. = $-0^{\circ}5894$
- 11 ALT correction for 1° alt. = $-0^{\circ}4122$
- 12 ALT correction for 2° alt. = $-0^{\circ}3075$
- 13 ALT correction for 3° alt. = $-0^{\circ}2408$
- 14 ALT correction for 4° alt. = $-0^{\circ}2014$
- 15 ALT correction for 5° alt. = $-0^{\circ}1700$
- 16 ALT correction for 6° alt. = $-0^{\circ}1444$
- 17 ALT correction for 7° alt. = $-0^{\circ}1252$
- 18 ALT correction for 8° alt. = $-0^{\circ}1105$
- 19 ALT correction for 9° alt. = $-0^{\circ}0988$
- 20 ALT correction for 10° alt. = $-0^{\circ}0894$

Appendix G. How to Determine Alignments with the Surveyor's Transit

We conclude the appendices to this chapter with a brief description of how to collect and analyze site alignments in the field.

The essential equipment for collecting such information consists of a reliable surveyor's transit (theodolite) with altitude and azimuth scales (Fig. 47) and a good watch. The watch may be set by time signals emanating from the shortwave radio station of the National Bureau of Standards, WWV (transmitting at 2.5, 5.0, 10.0, 15.0, and 20.0 megahertz), or radio station CHU of the Dominion Observatory, Canada (3.38 and 6.76 megahertz). If desired, the investigator may take a portable radio into the field to receive the time signals directly, but with a watch accurate to four or five seconds, this is hardly necessary. A copy of *The American Ephemeris and Nautical Almanac* for the year of observation is also useful. Computer programs for programmable calculators replete with the corrections discussed in this chapter are available to reduce the data (see, e.g., Appendix F). The data form depicted in Table 12 has been constructed for use in collecting and reducing the data. One data sheet is required for each alignment. Thus, it becomes necessary on extended trips to carry a looseleaf notebook containing several dozen such forms.

For an example of how typical field procedure is applied, refer to Table 12: It is desired to determine the true alignment of wall XX', in this case the base of the Castillo de Teayo, a small pyramid in Central Mexico. On the data form we enter the name of the site, its latitude and longitude (available on CETENAL maps, accurate to less than 1'), the date, and the description of the alignment. We also provide space on the form for a sketch showing the placement of the transit, T, and the sun, S. This is especially desirable when one wishes to recall the original situation for further analysis at a later time.

The observer places and levels the transit (according to instructions provided with that instrument) at X, close to the wall at a point where the original wall still lies intact. He or she then measures off the perpendicular distance between the base of the wall and the point where a plumb line from the transit strikes the ground. This distance is marked with a series of small nails at three or four reliable places along

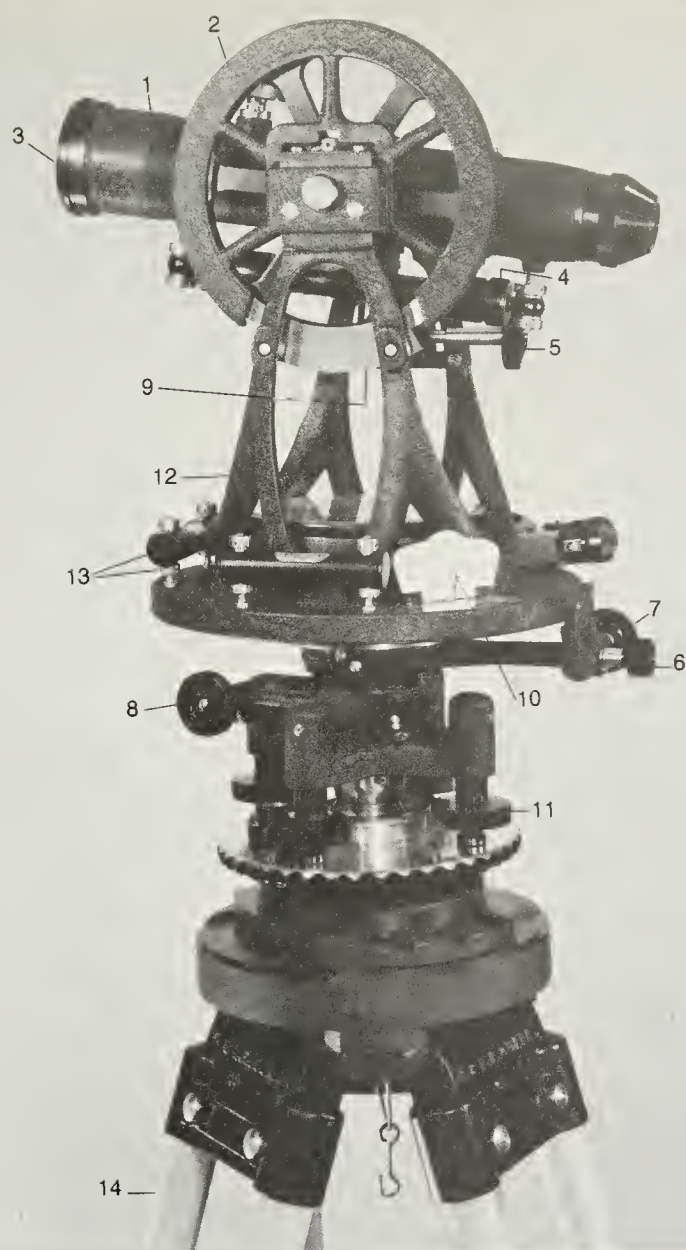


FIG. 47. The surveyor's transit and its principal parts: (1) telescope, (2) focusing knob, (3) eyepiece cap, (4) altitude clamp screw, (5) altitude fine setting, (6) azimuth clamp screw, (7) azimuth fine setting, (8) alternate azimuth clamp screw for use when same-scale reading is desired, (9) altitude scale, (10) azimuth scale, (11) leveling screws, (12) compass, (13) levels, (14) tripod. (Courtesy of Teledyne-Gurley Corporation, Troy, N.Y.)

the wall. Then azimuth readings on the arbitrarily oriented scale of the transit are recorded and averaged (see entries in the table for Align. AZ, rdg 1, 2, 3, 4, av.). Next, the telescope is raised to the level of the horizon and an altitude reading is taken (Horizon ALT).

To provide the correct information for altering the arbitrary azimuths to true azimuth readings, one observes a celestial body, usually the sun. The transit, equipped with a suitable sun filter, is directed at the sun, and that object is positioned precisely in the middle of the field (sets of vertical and horizontal crosswires are a necessary acces-

Table 12. Typical Data Form for Transit Observations

Site	Castillo de Teayo	Sketch
Alignment	Base of pyramid looking south	
Date	January 11, 1979	
Site latitude	20°35' N	
Site longitude	97°39' W	
Align. AZ rdg. 1	294°15'	
Align. AZ rdg. 2	294°25'	
Align. AZ rdg. 3	294°20'	
Align. AZ rdg. 4	294°20'	
Align. AZ rdg. av.	294°20'	
Horizon ALT	+1°45'	
Watch time	21:11:27	
Watch correction	+:39	
True GMT	21:12:06	
Sun AZ rdg.	339°54'	
Sun ALT rdg.	33°19'	
DEC sun	-21°47'	
Sun AZ calc.	233°40'	
Sun ALT calc.	33°16'	
EQ.T.	+00:07:45	
Align. AZ calc.	178°04'	
Magnetic	10° E of N	
Transit operators	PD, JS, AA	

sory on all transits). When the observer calls, “mark,” the watch is read (Watch time)¹⁹ and the azimuth and altitude readings of the sun (Sun AZ rdg., Sun ALT rdg.) are recorded. If the sun’s disk can be manually centered in the transit to within 1/2 minute of arc (1/60 of its own diameter), and a 2-second error is allowed on the watch, the method will be accurate to about one minute of arc. While this is already more precise than the deviation from a straight line of any wall one could ever expect to encounter, for long-distance base lines it may be equal to errors incurred by naked-eye sighting.

This concludes the observations. It is only necessary to record two additional items before proceeding with the tabulations on the programmable calculator. We enter into the appropriate spaces in Table 12 the declination of the sun (DEC sun) and the Equation of Time (EQ.T) (Table 13) for the date and time of the observation.²⁰

Next we use the first computer program from Appendix F to convert the arbitrary solar readings to true azimuth and altitude (Sun AZ calc., Sun ALT calc.). We also calculate the true azimuth of the alignment (Align. AZ calc.). Note that the (Sun ALT rdg.) and the (Sun ALT calc.) differ by only 3 minutes of arc. This fact serves as a partial verification of the alignment result; that is, we have used the sun azimuth reading to predict the correct altitude of the sun, which we already ob-

Table 13. *Approximate Values of the Equation of Time at Five-Day Intervals in the Tropical Year*

Date	Eq.T.	Date	Eq.T.	Date	Eq.T.
Jan. 0	+ 2 ^m 7	May 5	− 3.3	Sep. 2	− 0.4
5	+ 5.1	10	− 3.4	7	− 2.1
10	+ 7.3	15	− 3.7	12	− 3.8
15	+ 9.2	20	− 3.5	17	− 5.6
20	+10.9	25	− 3.1	22	− 7.3
25	+12.2	30	− 2.5	27	− 9.1
30	+13.3				
		Jun. 4	− 1.7	Oct. 2	−10.8
Feb. 4	+13.9	9	− 0.8	7	−12.2
9	+14.3	14	+ 0.2	12	−13.6
14	+14.3	19	+ 1.3	17	−14.7
19	+13.9	24	+ 2.3	22	−15.6
24	+13.3	29	+ 3.4	27	−16.1
Mar. 1	+12.3	Jul. 4	+ 4.3	Nov. 1	−16.4
6	+11.3	9	+ 5.2	6	−16.3
11	+10.0	14	+ 5.8	11	−15.9
16	+ 8.6	19	+ 6.2	16	−15.2
21	+ 7.1	24	+ 6.4	21	−14.1
26	+ 5.6	29	+ 6.4	26	−12.6
31	+ 4.1				
		Aug. 3	+ 6.1	Dec. 1	−10.9
Apr. 5	+ 2.8	8	+ 5.6	6	− 8.8
10	+ 1.3	13	+ 4.8	11	− 6.7
15	− 0.0	18	+ 3.7	16	− 4.3
20	− 1.2	23	+ 2.5	21	− 1.7
25	− 2.1	28	+ 1.1	26	+ 0.7
30	− 2.8			31	+ 3.1

Note: For more accurate values, see *American Ephemeris and Nautical Almanac* (any year).

served with the transit leveled precisely. The wall of the building (AZ = 178°04') is found to align almost true south, which implies that the façade faces close to due west. In the explanatory notes section of the data form, we indicate that the direction of the façade lies within 1½° of the sunset at the equinoxes. A prominent peak lies not too distant from the direction in question. A measurement of the azimuth and altitude of that peak was fed into the second computer program of Appendix F, which told us that sunsets eight days before vernal equinox and eight days after autumnal equinox occurred over the peak. In this particular example, taken from our field work of January 1979, when we reset the horizontal scale on the transit to read true azimuth we pointed the transit to true north; then we freed the balance on the magnetic compass attached to the transit and thus found the deviation of

magnetic from true north to be 10° . This information was useful when we wished to convert magnetic compass readings made and recorded at Teayo by earlier investigators to our more reliable true azimuth system.

ADDITIONAL READINGS

A thorough treatment of astronomical coordinate systems which includes an excellent set of exercises is given in *Practical astronomy*, by J. J. Nassau (New York: McGraw-Hill, 1948).

Discussions of field techniques in performing naked-eye astronomical measurements and calculations with special applications to astroarchaeology appear in:

- Anderson, S., and E. Fletcher. 1968. The inverse Stonehenge problem. *Current Anthropology* 9:316–318.
- Aveni, A. F. 1972. Astronomical tables intended for use in astroarchaeological studies. *American Antiquity* 37(4):531–540.
- Hawkins, G. S. 1966. *Astro-archaeology*. Research in Space Science, Special Report, no. 226. Cambridge, Mass.: Smithsonian Institution Astrophysical Observatory.
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- MacKie, E. 1977. *Science and society in pre-historic Britain*. New York: St. Martin's.
- Newton, R. 1974. Introduction to some basic astronomical concepts, in Symposium on the place of astronomy in the ancient world. *Philosophical Transactions of the Royal Society of London* 276:5–20.
- Thom, A. S. 1967. *Megalithic sites in Britain*. Oxford: Clarendon Press.
- . 1971. *Megalithic lunar observatories*. Oxford: Clarendon Press.
- Winkler, L. 1972. Astronomically determined dates and alignments. *American Journal of Physics* 40:126–132.

Other useful references which tabulate ancient celestial events in detail include:

- American ephemeris and nautical almanac*. U.S. Superintendent of Documents. Washington, D.C.: Government Printing Office. [Annually]
- Goldstine, H. 1973. *New and full moons 1001 BC to AD 1651*. Philadelphia: American Philosophical Society.
- Meeus, J., et al. 1965. *Canon of solar eclipses*. Oxford: Pergamon.
- Oppolzer, T. 1962. *Canon of eclipses*. New York: Dover.

IV. The Mathematical and Astronomical Content of the Mesoamerican Inscriptions

"It is, perhaps, as irrational to expect a satisfactory penetration of the mystic and emotional aura of the Maya philosophy of time by a creature of twentieth-century Western culture as it is to hope for a balanced, sympathetic and understanding study of the ecstasy of St. Francis from the pen of a militant atheist of our materialistic age. Our outlooks are too far from those of the Maya and, on top of that terrible handicap, there are so many aspects of the problem which are imperfectly known or completely unknown to us. The atheist student of St. Francis has at his disposal incomparably richer sources than we can ever dream of having."

—Sir Eric Thompson (Foreword to León-Portilla, 1973, p. viii)

A BRIEF HISTORY OF CALENDRIC DECIPHERMENT

To place in perspective our excursion into the Mesoamerican world of number, it might be worthwhile to trace the sinuous path that investigators have trod to arrive at the present state of their art. In the middle of the nineteenth century, the French Abbé Brasseur de Bourbourg, while serving as Catholic priest to the Quiché Maya of Guatemala, did much to bring the attention of the world to ancient Native American manuscripts, among them Bishop Landa's *Relación de las cosas de Yucatán*, a work written shortly after the conquest in 1566. Landa's identification of certain Maya symbols with sounds produced by letters of our own alphabet confused epigraphers for a long time about the true nature of Maya script, but his delineation of the day and month signs laid the base for the wave of calendric studies to follow. Brasseur translated and published several grammars, histories, and the Madrid Codex, a Maya picture book which he discovered. In the meantime, Lord Kingsborough, an itinerant Briton, published the *Antiquities of Mexico*, a huge collection consisting mostly of Mexican picture books. So monumental and costly was the work he undertook that Kingsborough died in a debtor's prison before he could complete a first edition. With the adaptation of photography to field techniques, British amateur archaeologist Alfred P. Maudslay produced the first set of stunning photographs of the inscribed Maya stelae of Copán in his *Archaeology* (*Biologia-Centrali Americana*) in 1889, a work which has been surpassed only today in the form of Ian Graham's *Corpus of Maya Hieroglyphic Inscriptions*.

By the end of the century the handful of scholars who had poured over the documents began to generate the first analyses of this mysterious calligraphy. Ernst Förstemann, a retired librarian, demonstrated the astronomical proficiency of the Maya by deciphering the Venus and lunar tables in the Dresden Codex as well as identifying many of the day, month, and number symbols. Historian Daniel Brinton published *A Primer of Mayan Hieroglyphics* (1895), and archaeologist Sylvanus G. Morley authored *An Introduction to the Study of Maya Hieroglyphs* (1915). Along with J. T. Goodman's "The Archaic Maya Inscriptions" (1897), in which the head-variant numerals were recognized, these works provided grist for the mill for future investigators while adding further definitive evidence that the civilizations of ancient America had risen to great heights in the fields of astronomy, calendar, and mathematics. Other notable names of the era around the turn of the century include the German Eduard Seler, who integrated many of the cosmological ideas of the Central Mexicans and the Mayas, and C. P. Bowditch of the Peabody Museum of Harvard University, who created an outstanding library for that institution and contributed to it with his *Numeration, Calendar Systems and Astronomical Knowledge of the Mayas* (1910).

John Teeple, a chemical engineer who dabbled in Maya hieroglyphs while engaged in train travel to professional meetings, opened up new vistas in 1930 with his publication of *Maya Astronomy*. He successfully identified many glyphs of the Supplementary, or Lunar, Series and contributed greatly to our understanding of Maya grammar by opening the gateway to the establishment of prefix and suffix glyphs. To him we are indebted for the elaboration of a scheme whereby the Maya tallied the difference between the tropical and vague years (determinant theory).

By the time Sir Eric Thompson published his landmark text, *Maya Hieroglyphic Writing*, in 1950,¹ Americanists began to realize that calendrics was not the only theme expressed in the hieroglyphs. Thompson's *Commentary on the Dresden Codex* (1972b) is a page-by-page excursion through the many almanacs contained in that Maya document. More than anyone, Thompson has best conveyed the flavor and spirit of Maya writing, exposing the many non-Western nuances implied in it and delineating the close connection of astronomy with astrology. Much of his work flourished during a period when the historical approach to the content of the glyphs began to be observed as a valid inquiry. Following the footsteps of Berlin (1958) who, in his study of emblem glyphs, was among the first to re-examine the Maya writing from a nonastronomical point of view, Proskouriakoff (1960) analyzed dates on stelae at Piedras Negras. She concluded that many of the inscriptions which epigraphers had read as strictly astronomical and calendrical in fact contained appellations and action glyphs. The identification of glyphs representing place names and rulers was a logical outcome of this shift of emphasis to the "historical hypothesis" and it signaled an exodus from the school of astronomical interpreters of glyphs. Today linguists have assumed an increased responsibility in the decipherment of Maya script.

A decade after Proskouriakoff's study, intensive work on the Pa-

lenque inscriptions led to the recognition of a dynastic sequence there. Such investigators as Lounsbury, Kelley, and Schele, who were also schooled in the astronomical, historical, and linguistic approaches, seized the opportunity to fuse these lines of attack. The new interdisciplinary attitude still persists. It has led to a number of remarkable discoveries at Palenque and holds promise for application to other inscriptional material. We might well have expected this marriage of dynastic history and astronomy to take place, for our understanding of Maya history has taught us that in their mind the domain of human affairs has never strayed far from the realm of cosmic events.

THE MESOAMERICAN PHILOSOPHY OF NUMBERS

Chronology was one of the basic motives for practicing astronomy in the ancient world. This is particularly true in Mesoamerica where the desire to create an ornate calendar developed into an obsession perhaps unparalleled in the history of human intellectual achievement.

For the Maya a single word, *kin*, signified time, day, and the sun. Its meaning and glyphic form (Fig. 61a) suggest that the art of time-keeping was intimately connected with the practice of astronomy. The directions of the petals of the floral design on the second and third kin glyph designs of Fig. 61a probably correspond to the extreme positions of the sun along the horizon. The various kin glyph forms, the diagrams of the world directions in the codices, and the quartered-circle petroglyphs to be analyzed in Chapter V all exemplify the space-related time system employed by the ancient Mesoamericans.

A brief look at the calendars displayed in Fig. 57 clearly demonstrates the union of space and time that the Mesoamerican mind sought to encompass. Also, the universality of the calendars becomes obvious. The division of each of these diagrams into four parts with the world at the center emphasizes the importance of the four world quarters. Notice the similarity between the calendar of Fig. 57a and the kin glyph. On the inner band we find a time division suggesting that the years march around the four quadrants, each one possessing its own direction. Each world direction had its associated god (*bacab*, or sky bearer) and color, a concept which was widespread throughout Mesoamerica. The Maya called the east *likin*, the direction "where the sun rises"; it was represented by the red color of the sunrise. The west (black for sunset) was *chikin*, meaning "where the sun sets." (The use of *kin* as second syllable signifies the paramount nature of the sunrise-sunset axis.) North, or *xaman* ("on the right hand of the sun"), was symbolized by white, and south, or *nohol* ("on the left hand of the sun"), was yellow.² The fifth cardinal direction, *yaxkin*, is the zenith through which the sun passes. Other examples are depicted in the Maya hieroglyphs of Fig. 53, particularly the Lamat sign. This habit of quartering the world and assigning colors to each of the four directions is also common among North American Indians (see, e.g., Wedel, 1977).

Whenever we witness a Maya inscription, almost always we are confronted with information about their multifaceted calendar. The

Maya recorded elaborate dates on upright stone slabs (stelae) as well as in manuscript form. Many of the classical inscriptions are magnificent works of art. Ancient architects often arranged their carved stelae at the most prominent position in the landscape of a ceremonial center.

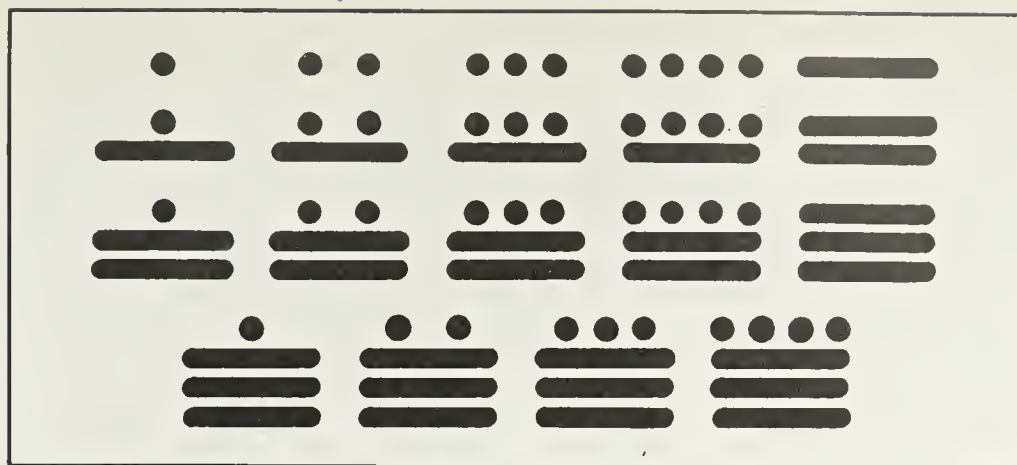
We can be sure that the movement of the great Maya time machine was closely tied to the cyclic repetition of celestial events and that the elaborate calendar was derived from careful observation of the heavens. In spite of the obstacles discussed in Chapters I through III and reviewed in the caption at the head of this chapter, in the pages ahead we seek to understand their theoretical methodology and to relate it to observational naked-eye astronomy.

We begin modestly enough by familiarizing ourselves with the mechanics of the mathematics and calendar of ancient Mesoamerica, a fascinating task which is necessary to interpret some of the simple dates inscribed on stelae and written on the handful of fragile manuscripts (codices) that survived the conquest. We will neither discuss nor interpret the nonastronomical segments of the corpus of hieroglyphic material. We shall try at specific points in the discussion to link the derivation of the calendrical concepts with the discussions of naked-eye astronomy in Chapter III and with the material on architecture and astronomical building orientation to follow in Chapter V. The discussion commences with a description of the Maya system of numeration and calendar.

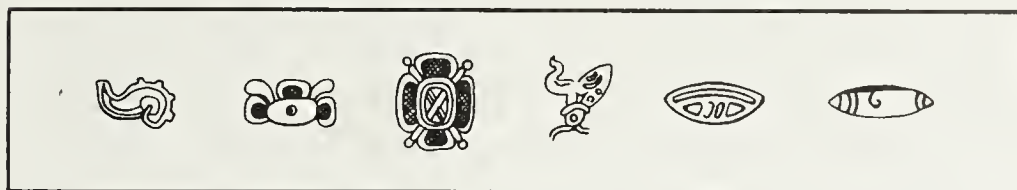
We dwell almost exclusively on Maya material, for within it we discover the highest degree of achievement in the field of astronomy within the Americas. More complete treatments than the elementary discussion of Maya hieroglyphs given here are available in the literature. The interested reader should consult the references at the end of the chapter for more advanced lessons in calendric decipherment—but be prepared for a challenge!

About half a millennium before the beginning of the Christian era a system of numeration developed in southern Mesoamerica. Probably emanating from the region of Monte Albán, Oaxaca (Marcus, 1976*b*), it was to become more refined than that in use anywhere else in the world at that time. Combinations of only three symbols were used to produce numbers written in the hundreds of millions: a dot was equivalent to one and a horizontal bar was equivalent to five, while a variety of symbols represented zero.

Paradoxically, for the Maya a zero represented completeness rather than emptiness. Temporally, it was regarded as the moment of completion of a cycle just as we regard the turning of a chain of nines to zeroes on the odometer of an automobile as the conclusion of a large-distance unit traveled. When we terminate our days, the clock registers 00 hours 00 minutes and 00 seconds, not because it has been turned back to its starting point but because the hands of the clock, like the sun in the sky they symbolize, have completed a daily cycle. A sea shell often represented the Maya zero, perhaps because its roundness was intended to depict the cyclic nature of time. The grasping hand, which like a knot ties up or bundles the days and years together into completed packages, also serves as a zero in many of the inscriptions. The dot and bar numerals, together with a few representations of zero, are



a



b

FIG. 48. (a) Maya dot and bar numerals 1–19; (b) the Maya devised a multitude of zero, or completion, symbols, some of which are represented here. (Diagrams by P. Dunham)






displayed in Fig. 48. In many cases they were highly stylized, the bars and dots being adorned with bows, knots, cross-hatched design, bandings, and other frills.

The introduction of the concept of zero into any mathematical system lends considerable facility to the performance of simple mathematical operations, especially when the position of a number in a series determines its value and contribution to the whole. The Maya expressed large numbers in a notational system utilizing place value, quite like our own system which was developed in the Middle East after the fall of the Roman Empire. Today, we write the number 365 without really being conscious of its meaning. This compact notation tells us that the number is the sum of 5 ones, 6 tens, and 3 ten-times-tens. We use a decimal or base-10 place system, undoubtedly because our ancestors counted articles on the fingers of both hands, defining a completed unit as that which was equivalent to the number of fingers possessed by a whole normal human being. Adding and subtracting becomes a simple operation when we can borrow or lend units readily between orders. Consider the difficulties associated with performing these simple operations in roman numeral notation, the scheme in use among the civilizations of Europe at the time the Maya employed their dot-bar system.

While place value and the concept of zero are two advanced features that the Maya system shares with our modern arabic notation, there are two primary differences. The Maya numbers were written















vertically, with place value increasing from bottom to top, and the base of the system was 20 instead of 10, making the higher places 20, 400, 8,000, 160,000, and so on, rather than 10, 100, 1,000, 10,000, and so forth. This so-called *vigesimal* system probably originated from the primitive habit of counting digits on both the hands and feet of the ancient Maya merchant. It seems reasonable that such a system would develop among tropical cultures.

To become more familiar with the dot-bar system in base 20, let us convert a large number, which we transliterate as 3.11.8.0.19, from Maya into arabic notation. Writing each positional count in arabic notation we have:

highest place	(20) ⁴		=	3	×	160,000	=	480,000
	(20) ³		=	11	×	8,000	=	88,000
	(20) ²		=	8	×	400	=	3,200
	(20)		=	0	×	20	=	0
lowest place	(1)		=	19	×	1	=	19

The sum of the numbers in the right-hand column is 571,219, the value of the number in decimal notation.

Though this vigesimal notation seems foreign to us, all the mathematical operations are as easy to execute as in the decimal system once the user becomes familiar with it. For example, should we desire to add the previous number to itself we must remember to carry a digit from a lower to the next-higher place only when the value of the lower place reaches twenty instead of ten. Thus, beginning our addition from the bottom, we have

		
		
	+	
	=	
		
		

or 7.2.16.1.18, which is equivalent to 1,142,438 in decimal notation. Occasionally, the Maya substituted grotesque head forms for the dots and bars, each honoring one of the many gods of the Maya pantheon, a fact which underlines the esteem in which the Maya held their numbering system. Unfortunately, the many variations of these forms make calendric decipherment a complicated business. In Fig. 49 some of the recognized head-variant forms of the numerals are shown. All of these appear in profile. Face numeral 1, identifiable by the conspicuous lock of hair, has been associated with a moon goddess. Numeral 2 shows an open hand above the head and symbolizes death and sacrifice. Three, with a turbanlike headdress often consisting of a disk with dots, symbolizes wind and rain. Four possesses a sun sign at the right, while 5 is the face of an old man. Six is easily recognizable by the axe symbol representing his eye. This god signifies rains and storms.

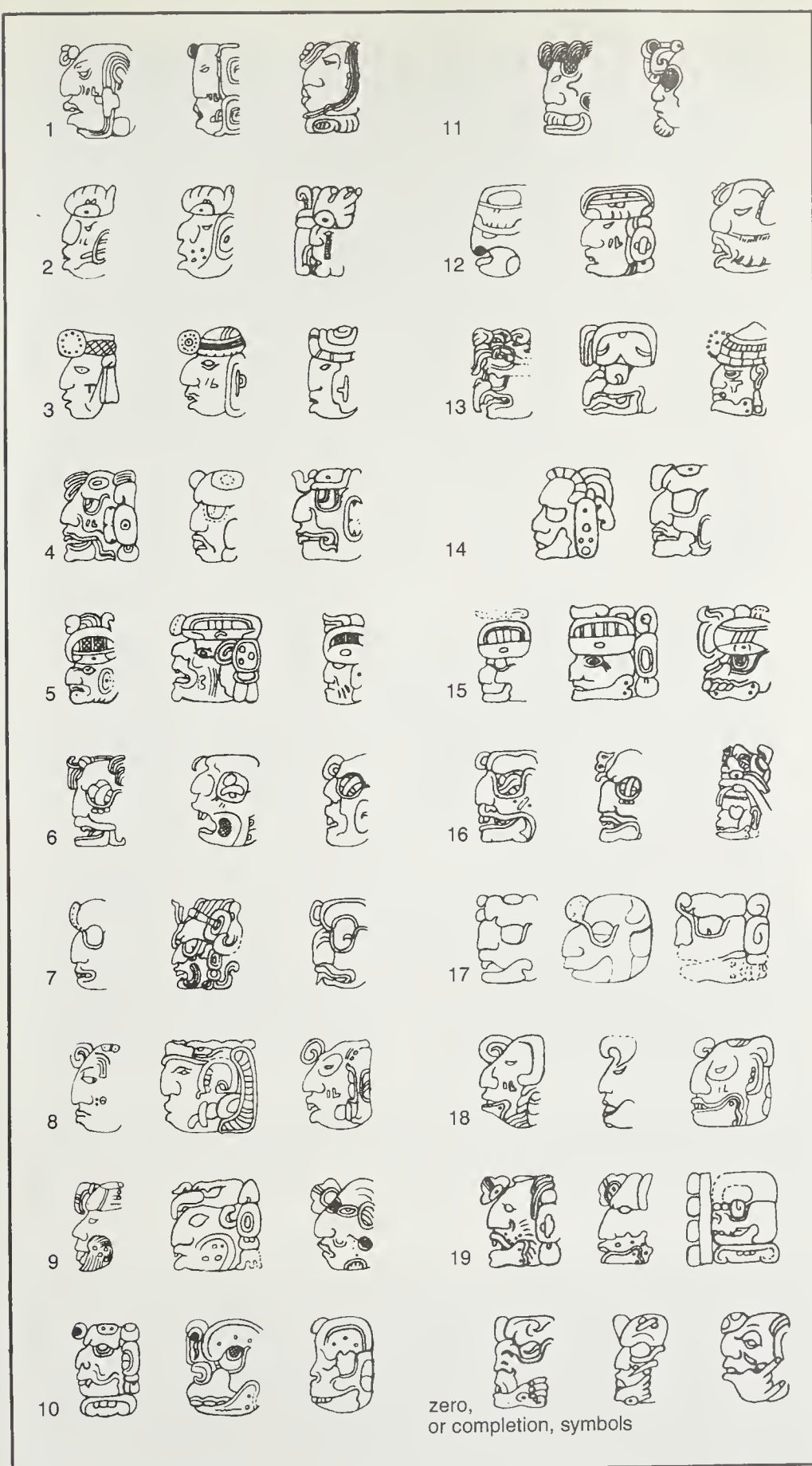


FIG. 49. Head-variant numerals. (Diagram by P. Dunham)



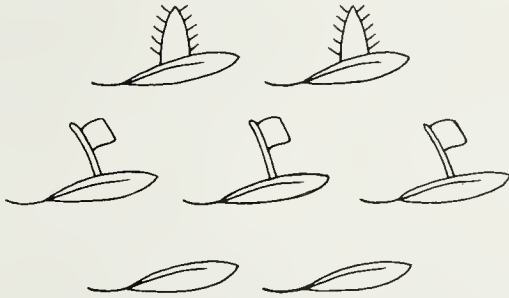
FIG. 50. Number gods adorn a Maya monument (Stela D, Copán). Each anthropomorphic figure (the left half of each compound hieroglyph) represents one of the twenty numerals. (Maudslay, 1889–1902, 1:pl. 48)

Seven symbolizes the night sun, and 8 the maize god; corn is visible in the latter's headdress. Number 9 has dots on his chin and represents a serpent. Ten is the first of a series of gods with a bared jawbone, a symbol of death. Eleven shows the earth-mountain symbol; 12, symbolic of Venus, has a "sky sign" over his head. Numbers 13 through 19 are variations on 3 through 9. Removal of the flesh from the jaw seems to signify that ten must be added to the lower numerals to obtain the higher ones.

Occasionally, full humanoid figures are employed to represent the

numbers. One of the most elegant examples of full-figure glyphs is revealed in the date carved on Stela D at Copán, Honduras (Fig. 50). A pair of zeroes, two stout fellows shown in glyph blocks A₃ and B₃,³ are easily recognizable by their hand-clasped jaws. One has his arm interlocked with an amphibian and the other grasps a manlike form with a grotesque left arm, each representing a time interval. These numbers are literally the bearers of time and they are depicted hauling or dragging the days along through history. Like the *cargadores* who still carry their loads through the streets of modern Mexico, the number figures of glyph blocks B₁ (number 9) and B₄ (number 8) carry their calendric cargo across eternity with a tumpline about the head. When they finally reach their destinations, they deposit their loads (time units) at a resting place, in this instance the great stone monument upon which their figures are struck, thus recording an important date in Maya history.

Likewise, in the Aztec picture-writing system of Central Mexico the orders also had symbols—a finger or no symbol at all for 1, a flag for 20, a tree for 400, and a bag for carrying copal incense for 8,000. These signs were often attached to the article being counted. Thus 862 feathers would be written:



Apparently, fractions were shunned, the Mesoamerican people preferring to deal in commensurate whole numbers. For example, the number 2,920 is divisible a whole number of times by 584 and 365. All three numbers are important in Maya calendrics. While Westerners might express 584 as $\frac{1}{5}$ of 2,920 and 365 as $\frac{1}{8}$ of 2,920, the Maya would state that if we were to add $365 + 365 + \dots$ (eight times) we would arrive at the same number as if we added $584 + 584 + \dots$ (five times). Addition and subtraction were probably the only mathematical operations they utilized.

THE LONG COUNT

When dealing with time, the ancient Mesoamericans abandoned the so-called trade count for a calendar count. They accomplished this by making one significant change in their numeration system. They altered the capacity of the third place to 18 units of 20, or a total of 360 instead of 400. This probably resulted when calendar keepers desired to bring the third place into close agreement with the tropical year of $365\frac{1}{4}$ days. Thus, the higher places became $20 \times 360 = 7,200$; $20 \times 720 = 14,400$; and so on.

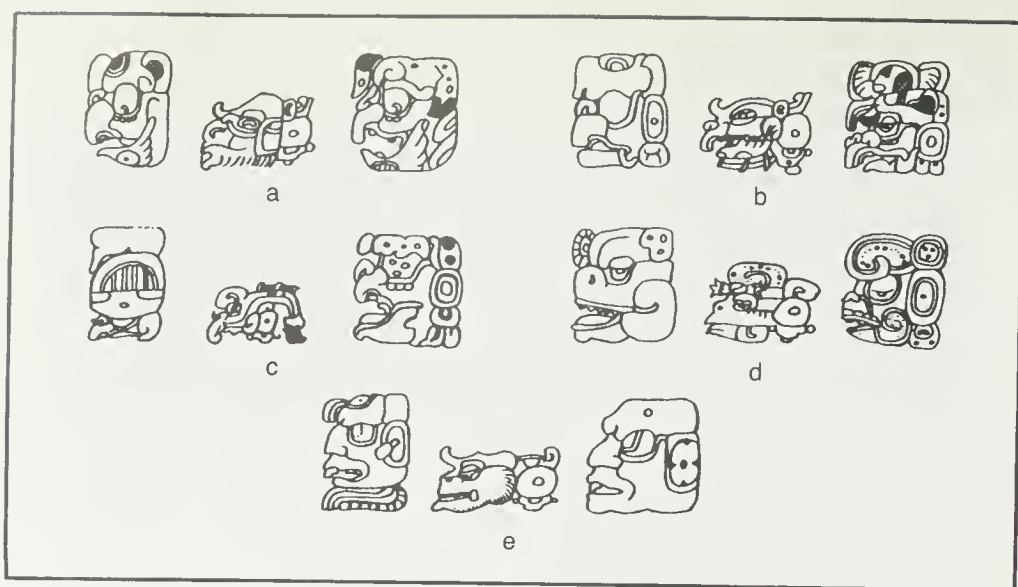


FIG. 51. Hieroglyphs representing orders of the Long Count of the Maya calendar: (a) baktun glyphs, (b) katun glyphs, (c) tun glyphs, (d) uinal glyphs, (e) kin glyphs (note the kin sign on the right ear of the figure comprising the last glyph). (Diagram by P. Dunham)

Each order of the calendrical count was named as follows (representative symbols for each of the periods are shown in Fig. 51):

1 day	=	1 kin
1 uinal	=	20 kins
1 tun	=	18 uinals = 360 kins
1 katun	=	20 tuns = 7,200 kins
1 baktun	=	20 katuns = 144,000 kins, etc. ⁴

We can think of the uinal as a 20-day month and the tun as a 360-day year. The uinal, in fact, may be a reformed lunar month since it contains the word moon (= *u*) while tun, the name of the 360-day unit, means "stone," possibly because the Maya carved a stone marker, or stela, when such an interval was concluded. Various multiples of the calendric units are given in Table 14.

Now, this would give a different value to the dot-bar number we wrote earlier should we be counting days instead of ears of corn.⁵ Using Table 14, we may refer our number 3.11.8.0.9 to a count of days; thus, 432,000 + 79,200 + 2,880 + 0 + 9 = 514,089 days. There is some evidence that the Maya actually viewed their time count as three separate systems, the basic units being the tun, the uinal, and the kin. In this case the previous number would be regarded in the Maya mind as 3.11.8 tuns, 0 uinals, and 9 kins. The duration of the period is, nevertheless, the same. So special were time units that the Maya felt it necessary to use a different counting system when dealing with them.

One of the primary statements in the Maya calendric record is the Long Count, or the number of days having elapsed since a fixed point in the distant past.

Maya Long Count dates began at 0.0.0.0.0, a prehistoric date marking the most recent creation period. After the first day was completed, the Long Count time machine clicked forward one unit to 0.0.0.0.1; after the second day, to 0.0.0.0.2, and so forth—operating like the

Table 14. *Days per Given Number of Maya Calendric Units in the Long Count*

<i>Number</i>	<i>Baktuns</i>	<i>Katuns</i>	<i>Tuns</i>	<i>Uinals</i>	<i>Kins</i>
1	144,000	7,200	360	20	1
2	288,000	14,400	720	40	2
3	432,000	21,600	1,080	60	3
4	576,000	28,800	1,440	80	4
5	720,000	36,000	1,800	100	5
6	864,000	43,200	2,160	120	6
7	1,008,000	50,400	2,520	140	7
8	1,152,000	57,600	2,880	160	8
9	1,296,000	64,800	3,240	180	9
10	1,440,000	72,000	3,600	200	10
11	1,584,000	79,200	3,960	220	11
12	1,728,000	86,400	4,320	240	12
13	1,872,000	93,600	4,680	260	13
14	2,016,000	100,800	5,040	280	14
15	2,160,000	108,000	5,400	300	15
16	2,304,000	115,200	5,760	320	16
17	2,448,000	122,400	6,120	340	17
18	2,592,000	129,600	6,480	—	18
19	2,736,000	136,800	6,840	—	19

odometer of an automobile, until a cycle of 13 baktuns, 13.0.0.0.0., representing a creation epoch, was completed. After this elapsed period, a little over 5,000 years, the count returned to zero and another cycle began.⁶

The concept of the cyclic destruction and rebirth of the world is a common theme in Mesoamerican religion and mythology. On the famous Aztec calendar stone (Fig. 11), surrounding the face of the Sun God, about whom all periodic phenomena in nature take place, we see four rectangular panels symbolizing the destruction of the world on each of the previous epochs through which it has passed. In the most remote epoch (upper right), giants who inhabited the earth were attacked and devoured by jaguars. At the upper left, the god of wind symbolizes the hurricanes that carried away the people of the second epoch. The third cosmogonic epoch, symbolized by the god of fire-rain at the lower left, was destroyed by lava and fire in a great volcanic eruption. The few survivors were those who were able to transform themselves into birds. Storms and torrential rains epitomized by the water god ending the fourth epoch (lower-right panel) caused men to be changed into fishes. In the present, or fifth, epoch destruction by earthquake is said to await us. Recently, Townsend (1979) has given a complete analysis of the content of the calendar stone.

To obtain the equivalent in our own Gregorian, or "Christian," calendar of any Long Count date appearing in the Maya inscriptions, we must be able to match with certainty at least one Long Count date with a date in the Gregorian calendar. However, there is considerable

disagreement about how to do this. According to one of the most widely accepted attempts to correlate the Maya and Christian calendars, the so-called Goodman-Martínez-Thompson (abbreviated GMT) correlation, the zero-point of the most recent starting position of the Long Count was August 12, 3113 B.C., a date on which astronomers have found no significant celestial event to have occurred. The subject of the correlation of the Maya and Christian calendars is both complicated and confusing. More than a dozen correlations have been proposed, each one certified as correct by its inventor. We defer our discussion of the correlation question to Appendix A at the end of the chapter. For the time being, any Christian dates we encounter will be converted from the Maya according to the GMT correlation. (In Appendix B we introduce a simple scheme for date conversion.)

The Maya were diligent record keepers during baktuns 8, 9, and 10 of the most recent cycle, since most of the dates we encounter have one of these numbers in the highest place;⁷ for example, we find Long Count dates like 9.15.11.16.2. With the help of Table 14, we can break this date down into the sum of

9 baktuns	×	144,000 days	=	1,296,000 days
15 katuns	×	7,200 days	=	108,000 days
11 tuns	×	360 days	=	3,960 days
16 uinals	×	20 days	=	320 days
2 kins	×	1 day	=	2 days,

or 1,408,282 days after zero day, equivalent to A.D. May 9, 743 GMT.

Let us now examine a real Long Count date as the epigrapher might encounter it. The right half of Fig. 52 shows one of the earliest inscriptions, that found on one side of a carved jade plaque called the Leyden Plate after the city in the Netherlands in whose museum it is located. Originally discovered on the east coast of Guatemala, it gives the accession date of the chieftain, a ruler of Tikal, on the reverse side (left). The date begins at block 1 with an elaborate introductory glyph, quite common on dated Maya monuments. We then read in descending order, blocks 2 through 6: 8 baktuns, 14 katuns, 3 tuns, 1 uinal, 12 kins, corresponding to about A.D. 320. (Hieroglyphs symbolizing the time periods should be recognizable in Fig. 51.)

THE CALENDAR ROUND

The additional hieroglyphs in block 7 and in the blocks comprised of rows 8–11, columns A and B, of Fig. 52 suggest there must be more to a Maya date than the Long Count. At least two other fundamental time periods are represented in the rest of the Leyden inscription: the position in the ritual almanac, also called the Tzol kin, or simply the 260-day cycle (called Tonalpohualli by the Aztecs), and the vague year of 365 days, or Haab (called Xihuitl by the Aztecs). The Long Count, vague year, and ritual cycle, taken together, constitute the Initial Series portion of a Maya date. These are the first symbols one usually encounters in a calendric inscription.

We find the earliest example of the 260-day calendar (about 600 B.C.) at the ruins of San José Mogote near Monte Albán. The cycle, evi-

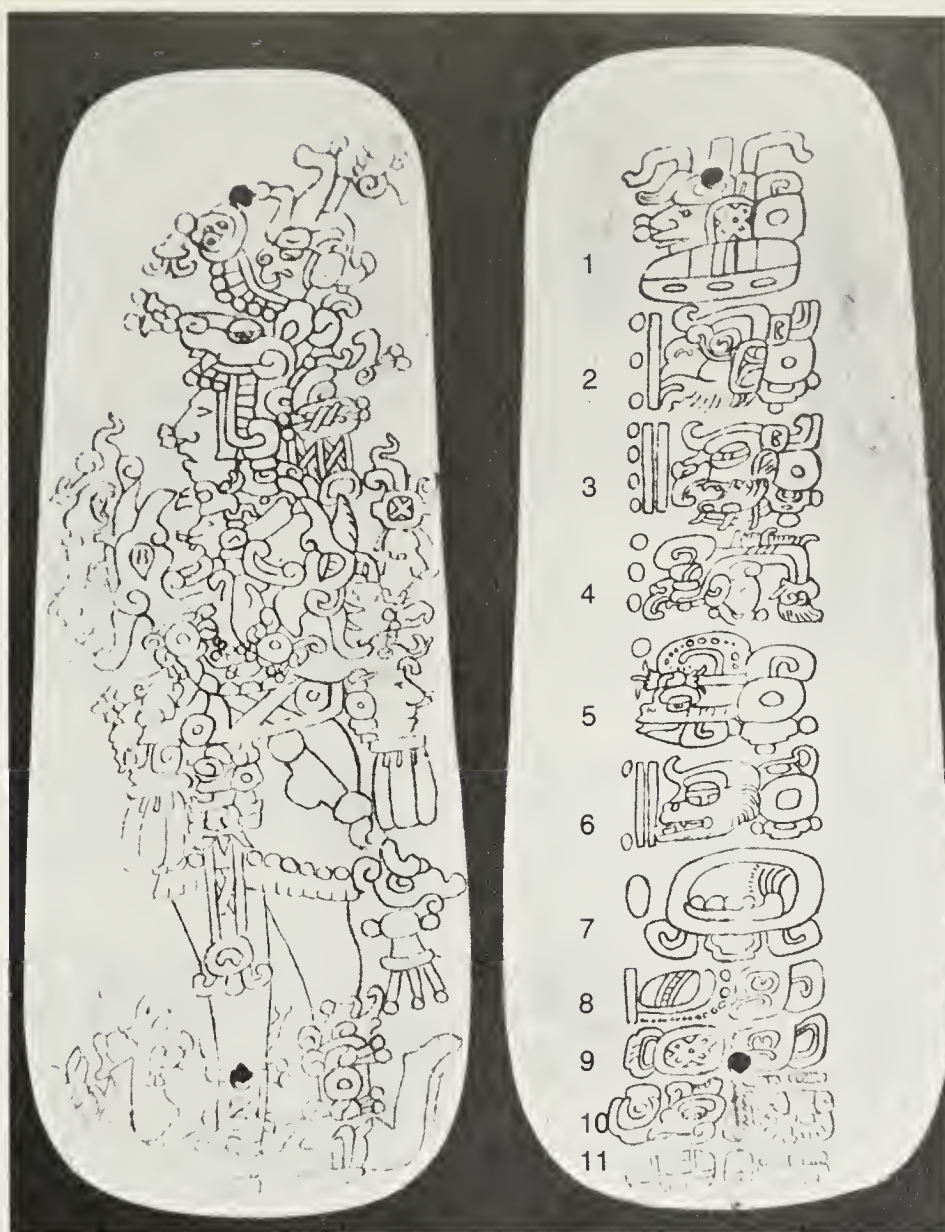


FIG. 52. The Leyden Plate (30 cm long). (Morley, 1961, pl. 15; courtesy of Carnegie Institution of Washington)

dently the earliest calendric form for which we have documentation, consists of twenty named days alternated endlessly with numerals 1 through 13, the two cycling together independent of the Long Count. We can think of the Tzol kin as a pair of gears, one with thirteen cogs, the other with twenty. These gears were without a doubt the most important components of the Maya time machine. The day names used by both the Maya and the Aztecs are listed in Table 15 and representative Maya day hieroglyphs are pictured in Fig. 53.⁸ The Aztecs had their own names and symbols; otherwise, the units and calendar mechanics are essentially the same. We can see the Aztec pictures which represent each of the twenty days on the circular band surrounding the central portion of the Aztec calendar stone in Fig. 11.

Suppose we start a cycle today by matching number 1 with day Imix; then tomorrow will be 2 Ik and the next day 3 Akbal. Looking

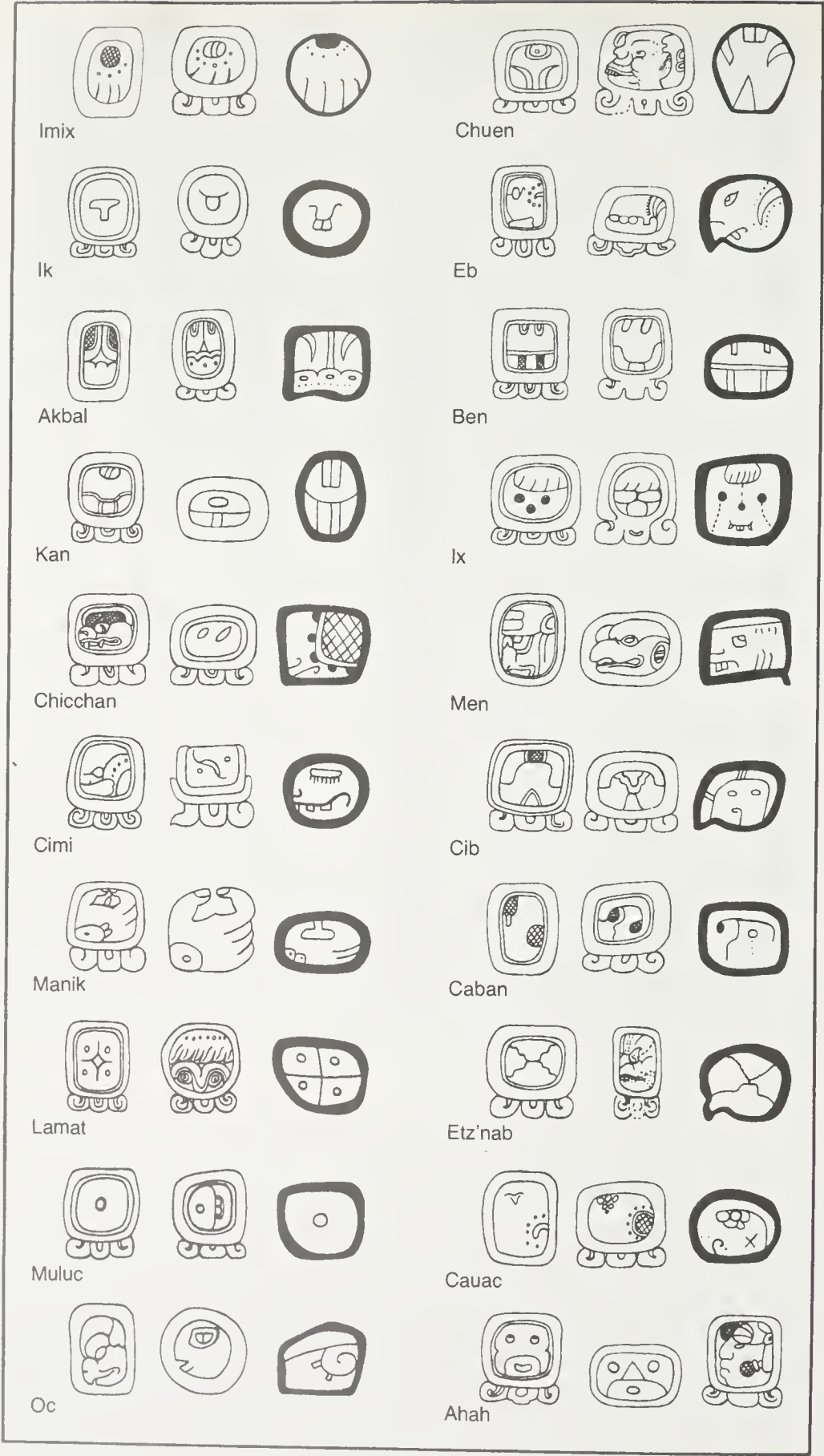


FIG. 53. Day name glyphs (see Table 15). Those heavily outlined are examples taken from the codices; the others are from stelae. (Diagram by P. Dunham)

Table 15. *Maya Day and Month Names with Central Mexican Counterparts*

	<i>Maya</i>	<i>Aztec</i>
Day Names	Imix	Cipactli (alligator)
	Ik	Ehécatl (wind)
	Akbal	Calli (house)
	Kan	Cuetzpallin (lizard)
	Chicchan	Cóatl (serpent)
	Cimi	Miquiztli (death)
	Manik	Mázatl (deer)
	Lamat	Tochtli (rabbit)
	Muluc	Atl (water)
	Oc	Itzcuintli (dog)
	Chuen	Ozomatli (monkey)
	Eb	Malinalli (grass)
	Ben	Acatl (reed)
	Ix	Océlotl (jaguar)
	Men	Cuauhtli (eagle)
	Cib	Cozcacuauhtli (buzzard)
	Caban	Ollin (movement)
	Etz'nab	Técpatl (flint knife)
	Cauac	Quiáhuitl (rain)
	Ahau	Xóchitl (flower)
Month Names	Pop	Tlaxochimaco
	Uo	Xocotlhuetzli
	Zip	Ochpaniztli
	Zotz	Teotleco
	Tzec	Tepeilhuitl
	Xul	Quecholli
	Yaxkin	Panquetzaliztli
	Mol	Atemoztli
	Chen	Tititl
	Yax	Izcalli
	Zac	Atlcahualo
	Ceh	Tlacaxipeualiztli
	Mac	Tozoztontli
	Kankin	Hueytozoztli
	Muan	Tóxcatl
	Pax	Etzalcualiztli
	Kayab	Tecuilhuitontli
	Cumhu	Hueytechuilhuitl
	Uayeb	Nemontemi

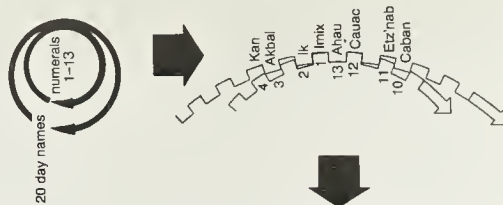
Note: Alignment of Aztec month names with Maya month names after Spinden (1924, p. 103).

through the ordered list of day names, we see that day number 13 will be Ben. We then begin the number series again, matching 1 with Ix, 2 with Men, 3 with Cib, and so. After 7 Ahau we run out of named days and must return to the beginning of the list for 8 Imix. There will be other numerals to match day Imix but the same number and day combination will not repeat until 13×20 , or 260, days have elapsed (13.0 in Maya notation). This cycle is rather like our own scheme of matching seven named weekdays with the numbered days of the month, except that our system is not so orderly—some of our months have 30 days, some 31, and, occasionally, some 28 or 29. In Fig. 54 we combine the 13- and 20-day gears to form a calendar wheel with 260 teeth showing all possible combinations of number and day name, each being represented by a cog in the wheel. The count starts arbitrarily with the date 1 Imix and proceeds through the 260-day cycle back to the original position. For convenience in using the wheel for computation a little later, we attach a running number between 1 and 260 to the inside track.

No other civilization in the world used a 260-day cycle, and we cannot be sure how this peculiar period rose to prominence in Mesoamerica. It is still employed among some remote people of the highland region of Guatemala in the present century. B. Tedlock (1979) has shown that the day names still function for the Quiché Maya and that they possess literal as well as symbolic meaning. For example, only certain days are considered favorable for the asking of a hand in marriage, others for the marriage ceremony itself. Similar prognosticatory functions are found for Venus appearance and disappearance times in the ancient Maya calendar, as we shall illustrate later in this chapter. This segment of the Maya calendar indeed remains a living relic.

According to one explanation, the 260-day ritual count originated at Copán, which is situated in such a latitude ($14^{\circ}57' \text{ N}$) that the passages of the sun across the zenith divide the year into parts that are 260 and 105 days in length (see Table 3). These periods approximate the long and short planting seasons still in use today. Still, this hypothesis seems disturbing, especially since we find evidence in the Zapotec area of calendric inscriptions dating back to 600 B.C., long before Copán was settled. The city, though founded much later, nevertheless may have been deliberately situated at the correct latitude.

Alternatively, it has been proposed that the zenith principle was discovered at the Late Pre-Classical site of Izapa in western Mexico, which is situated at the same latitude as Copán but farther west. The principle was then applied in the east to determine the location of Copán by seeking a suitable site at the proper latitude. Many people have objected to any hypothesis for the origin of the cycle which involves astronomical events since no heavenly phenomena occur regularly at the same point in the cycle. Since the 260-day count ran continuously, a given day in the cycle would occur at different points in succeeding tropical years, whereas the zenith passages occur at fixed points in all tropical years. Perhaps such an argument reflects our own cultural bias about how astronomy ought to be practiced. Nevertheless, it is an intriguing coincidence to find that the August 12 zero date of the Long Count according to the GMT correlation coincided exactly



Imix	1(1)	8(21)	2(41)	9(61)	3(81)	10(101)	4(121)	11(141)	5(161)	12(181)	6(201)	13(221)	7(241)
Ik	2(2)	9(22)	3(42)	10(62)	4(82)	11(102)	5(122)	12(142)	6(162)	13(182)	7(202)	8(222)	9(242)
Akbal	3(3)	10(23)	4(43)	11(63)	5(83)	12(103)	6(123)	13(143)	7(163)	8(183)	9(203)	10(223)	11(243)
Kan	4(4)	11(24)	5(44)	12(64)	6(84)	13(104)	7(124)	8(144)	9(164)	10(184)	11(204)	12(224)	13(244)
Chochan	5(5)	12(25)	6(45)	13(65)	7(85)	1(105)	8(125)	9(145)	10(165)	11(185)	12(205)	13(225)	1(245)
Cimi	6(6)	13(26)	7(46)	1(66)	8(86)	2(106)	9(126)	10(146)	11(166)	12(186)	13(206)	1(226)	2(246)
Mank	7(7)	1(27)	8(47)	2(67)	9(87)	3(107)	10(127)	4(147)	5(167)	6(187)	7(207)	8(227)	9(247)
Lamat	8(8)	2(28)	9(48)	3(68)	10(88)	4(108)	11(128)	5(148)	6(168)	7(188)	8(208)	9(228)	10(248)
Muluc	9(9)	3(29)	10(49)	4(69)	11(89)	12(109)	13(129)	1(149)	2(169)	3(189)	4(209)	5(229)	6(249)
Oc	10(10)	4(30)	11(50)	5(70)	12(90)	6(110)	7(130)	8(150)	9(170)	10(190)	11(210)	12(230)	13(250)
Chuen	11(11)	5(31)	12(51)	6(71)	13(91)	7(111)	8(131)	9(151)	10(171)	11(191)	12(211)	13(231)	1(251)
Etz	12(12)	6(32)	13(52)	7(72)	8(92)	9(112)	10(132)	11(152)	12(172)	13(192)	1(212)	2(232)	3(252)
Ben	13(13)	7(33)	1(53)	8(73)	2(93)	3(113)	4(133)	5(153)	6(173)	7(193)	8(213)	9(233)	10(253)
Ix	1(14)	8(34)	2(54)	9(74)	3(94)	10(114)	11(134)	12(154)	13(174)	1(194)	2(214)	3(234)	4(254)
Men	2(15)	9(35)	3(55)	10(75)	4(95)	11(115)	12(135)	13(155)	1(175)	2(195)	3(215)	4(235)	5(255)
Cib	3(16)	10(36)	4(56)	11(76)	5(96)	12(116)	13(136)	1(156)	2(176)	3(196)	4(216)	5(236)	6(256)
Caban	4(17)	11(37)	5(57)	12(77)	6(97)	13(117)	1(137)	2(157)	3(177)	4(197)	5(217)	6(237)	7(257)
Etz'nab	5(18)	12(38)	6(58)	13(78)	7(98)	1(118)	2(138)	3(158)	4(178)	5(198)	6(218)	7(238)	8(258)
Cauac	6(19)	13(39)	7(59)	1(79)	8(99)	2(119)	3(139)	4(159)	5(179)	6(199)	7(219)	8(239)	9(259)
Ahau	7(20)	1(40)	8(60)	2(80)	9(100)	3(120)	4(140)	5(160)	6(180)	7(200)	8(220)	9(240)	10(260)

FIG. 54. The Tzol kin wheel of the days: a combined count of 13 numerals and 20 named days formed the basic calendar cycle of 260 days. The entire cycle is delineated in the adjoining table. (Diagram by P. Dunham after Teeple, 1930, p. 89)

with solar zenith passage at the Copán latitude. It is also an interesting coincidence that this date lies close to either a solstice or an equinox in correlations proposed by Escalona Ramos, Smiley, Hochleitner, and Kelley.

Other astronomical events have been casually related to the 260-day count. A double Tzol kin of 520 days (1.8.0 in Maya) is almost exactly equivalent to three eclipse half-years (3×173.31 days = 519.93 days), a factor which could have been of importance in the prediction of eclipses (see Chapter III). Furthermore, the actual appearance interval of Venus as morning and evening star is close to 260 (263 days on the average), and Mars' synodic period is exactly three cycles of 260 days. Also, the 260-day cycle is remarkably close to the average gestation period of the human female, which would imply a very practical origin for the length of the cycle. Finally, the cycle may have had no connection whatsoever with natural phenomena. It could have resulted simply from the combination of the fundamental numbers 20 and 13.

The coincidence between the duration of visibility of Venus in the sky and the 260-day calendar leads us to wonder whether the two cycles were connected empirically. Extracts from a manuscript by Friar Toribio Motolinía supply some rather definitive evidence on this question. We find the following explanation accompanying a table of day names for one 260-day cycle:

... here is explained the calendar or table of the star named Hesper, or, in the language of the Indians, Hueycitlalin or Totonametl.

The table given here can be designated as the calendar of the Indians of New Spain, which they counted by a star which, in the autumn, begins to appear, toward evening, in the west with a clear and resplendent light. Indeed, those who have good eyesight and know where to look for it can perceive it from mid-day on.

This star is that we call Lucifer, etc. . . . As the sun goes lower and the days grow shorter the star seems to rise—thus each day it appears a little higher until the sun seems to reach it and pass it in the summer and spring when it sets with the sun and is visible through its light.

And in this land the duration of time from the day when it first appears to when after rising on high it loses itself and disappears, amounts to 260 days, which are figured and recorded in said calendar or table. (Nuttall, 1904, pp. 497-498)

Except for the confusion about the seasonal recurrence of the phenomenon, there can be little doubt that Motolinía is talking about the planet Venus, for it is the only object in the sky that behaves as described within the period he defines. To strengthen the argument, Motolinía goes on to state that the same object lingers and rises in the east for another 260-day period and that the Aztecs followed it very closely and worshipped it because they believed that Quetzalcóatl transformed himself into this star when he left our world.

Finally, Kelley (private communication) has suggested that the cycle originated from *metztli*, a standardized sidereal month of 28 days, multiplied by 13 to give a 364-day year. He believes the 260 originated when the "number box" was reduced from 28 to 20, thus:

1	2	3	4	5	6	7	8
28	1	2	3	4	5	6	9
27	20					7	10
26	19					8	11
25	18					9	12
24	17					10	13
23	16	15	14	13	12	11	14
22	21	20	19	18	17	16	15

Given the astronomical, numerological, and biological coincidences, there is the feeling that, regardless of its origin, the number grew to be significant precisely because the Maya recognized how manifestly it reflected so many of nature's cycles.

The final part of an Initial Series date records the position in the so-called vague year of 365 days. This is formed by alternating eighteen named month positions (Table 15) with the numbers 0–19, totaling 360 days. A nineteenth period, not really a month, called Uayeb (Nemontemi in Aztec), consisting of 5 numbered days, each said to be unlucky, is tacked on at the end to form the complete 365-day round. Like our February 29, it is an extra period added on to the normal year, though not for the same reason. Hieroglyphic representations of the month names are given in Fig. 55. The vague year operates independently of the 260-day ritual almanac and the Long Count, just as our sequence of named days Sunday-Monday-Tuesday rolls along without being affected by the day number and month sequence. If we begin a Maya vague year with 0 Pop (day zero of the month of Pop), the next day will be 1 Pop and the month will end with 19 Pop. This will be followed by 0 Uo, and so on. The 360th day of the year would be 19 Cumhu to be followed by 0 Uayeb. The year ends with 4 Uayeb; then we have New Year's Day of the next year, 0 Pop again.⁹ This series, like the 260-day cycle, marches on endlessly without change, unaffected by the other parts of the Initial Series. A sectioned Haab wheel fashioned in the manner of the Tzol kin wheel is shown in Fig. 56. The inner portion of the wheel numbers the days from 0 Pop.

Now, imagine that the "calendar gears" of Figs. 54 and 56 fit together. Though they roll along eternally, after a certain length of time a position in the 260-day count will recur at a given position in the 365-day count. A completed cycle, or Calendar Round, is defined as the length of time elapsing between successive occurrences of a given numbered and named day in the 260-day count with the same number and month position in the 365-day year. Such a complete date will repeat every 18,980 days, the least common multiple of 260 and 365. This period is equal to 73 Tzol kin, or 52 vague years.



FIG. 55. Month name glyphs (see Table 15). Those heavily outlined are examples taken from the codices; the others are from stelae. (Diagram by P. Dunham)

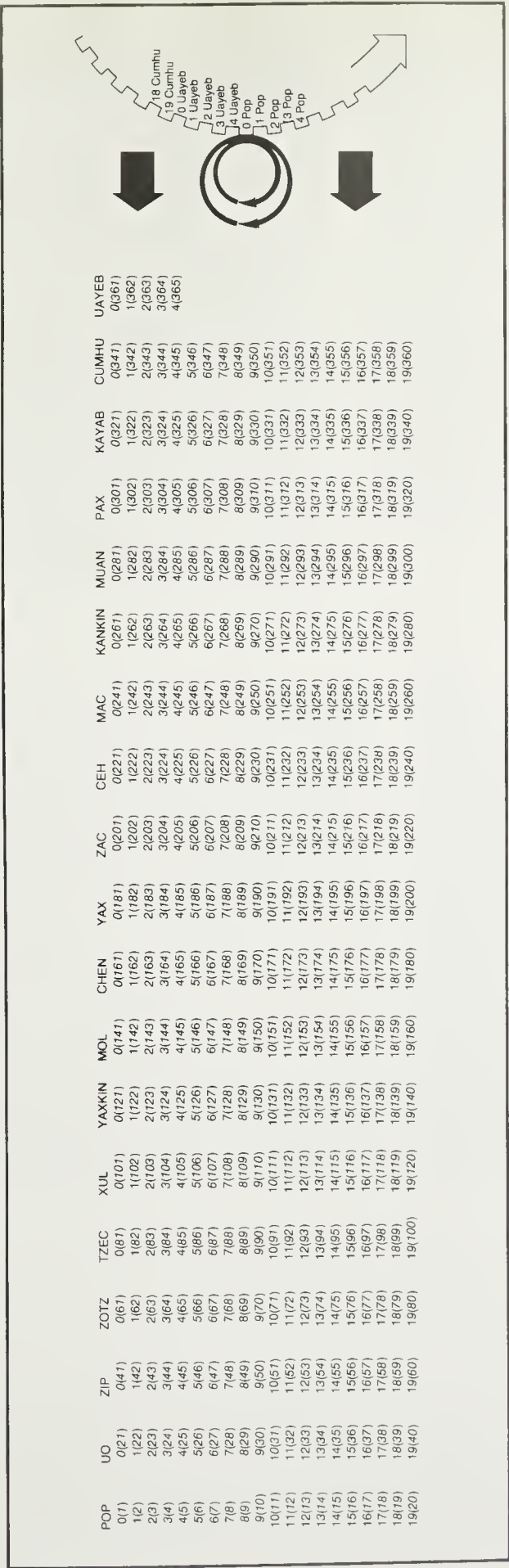


FIG. 56. A Haab cycle, or wheel of the months: 18 months, each of 20 days, plus an additional period of 5 days make up a 365-day cycle. This “gear” meshes with those of FIG. 54 to produce a calendar round of 52 years. The entire cycle is delineated in the adjoining table. (Diagram by P. Dunham)

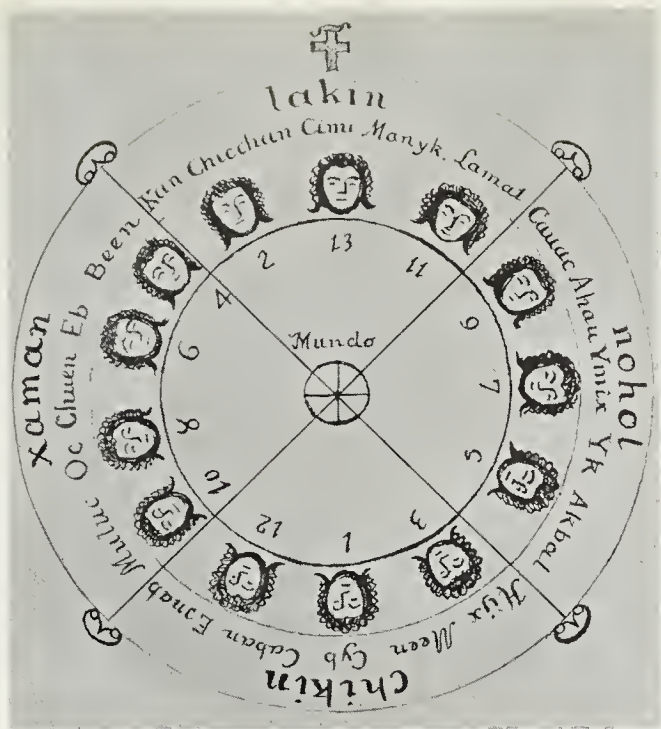
As was suggested in Chapter III, the 52-year cycle was a time period of great significance throughout all Mesoamerica. In Central Mexico, where it was called the *Xuihmolpilli* (the binding, or bundling, of the years), the termination of each cycle was celebrated by a New Fire ceremony. The postconquest historian Sahagún tells what happened on this occasion:

When (came) the time of the binding of our years, always they gradually neared and approached (the year) Two Reed. This is to say: they then reached and ended (a period of) fifty-two years. For at that time (these years) were piled up, added one to another, and brought together; wherefore the thirteen-year (cycles) and four times made a circle, as hath been made known. Hence was it said that then were tied and bound our years, and that once again the years were newly laid hold of. When it was evident that the years lay ready to burst into life, everyone took hold of them, so that once more would start forth—once again—another (period of) fifty-two years. Then (the two cycles) might proceed to reach one hundred and four years. It was called "One Old Age" when twice they had made the round, when twice the times of binding the years had come together.

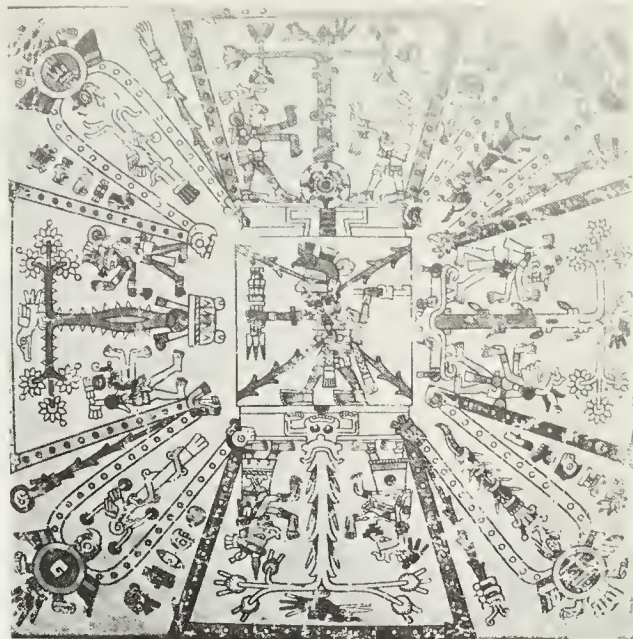
Behold what was done when the years were bound—when was reached the time when they were to draw the new fire, when now its count was accomplished. First they put out fires everywhere in the country round. And the statues, hewn in either wood or stone, kept in each man's home and regarded as gods, were all cast into the water. Also (were) these (cast away)—the pestles and the (three) hearth stones (upon which the cooking pots rested); and everywhere there was much sweeping—there was sweeping very clear. Rubbish was thrown out; none lay in any of the houses. (1953, p. 25)

As the passage suggests, every 52-year period was divided into four 13-year portions, each headed by a different year bearer representing a given cardinal direction. Such a quadripartition is repeatedly depicted in a variety of ways in the ancient world diagrams that survive in print. Now that we are better equipped to understand the time cycles involved in such a four-part division, let us return to the calendars of Fig. 57 and examine them in greater detail.

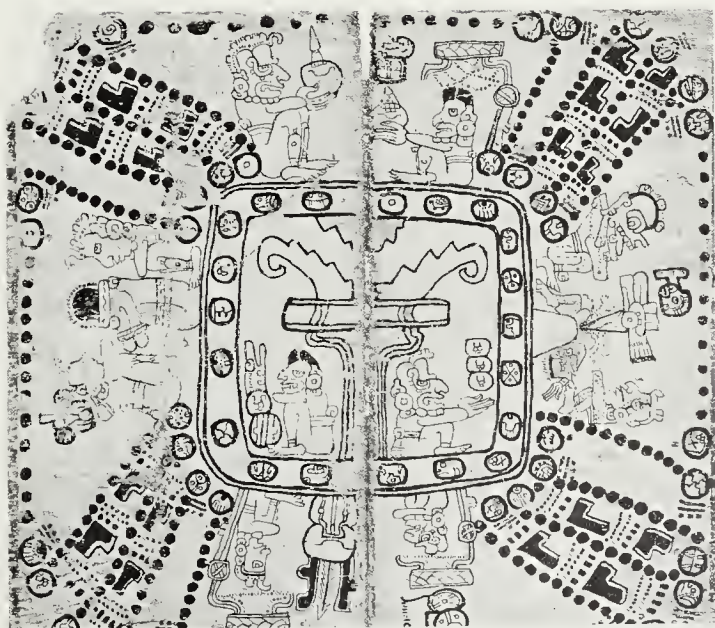
The diagram depicted in Fig. 57*a* is taken from one of the Yucatecan religious texts, the *Book of Chilam Balam of Kaua* (Bowditch, 1910, fig. 64), written about the time of the conquest. A pair of lines intersecting at right angles divides the wheel into four compartments, each representing a region of the world. Within lie thirteen *katun* time periods divided 3-3-3-4, each numbered and symbolized by a head. We begin a year with the five days Kan, Chicchan, Cimi, Manik (Manyk), and Lamat, and these five days also end the year. Kan, the first day of the year, is termed the "year bearer" and the Kan years are



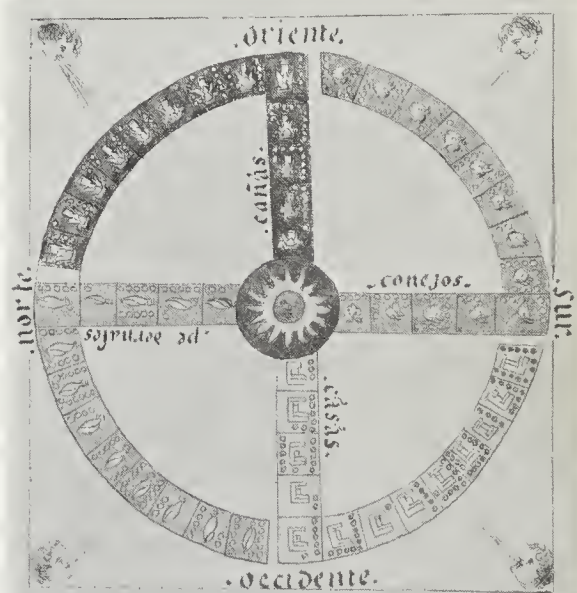
a



b



c



d

FIG. 57. A selection of Mesoamerican calendars from the codices. (a Bowditch, 1910, fig. 64, courtesy of Cambridge University Press; b and c courtesy of Akad. Druck-u. Verlag, Graz; d Durán, 1971, pl. 35, Copyright 1971 by the University of Oklahoma Press)

said to be associated with the east (*lakin* = *likin*). Then comes the year having Muluc for year bearer and the five days Muluc, Oc, Chuen, Eb, and Ben (Been), which are associated with the north (*xaman*). In this manner the years march counterclockwise around the horizon, four to a cycle, returning to the east. The small circle at the center (labeled *mundo* in Spanish) represents the earth, from which the four direc-

tions are reckoned. It too is quartered, but by a pair of intersecting lines lying midway between those which divide the outer portions of the circle. These signify the cardinal directions, while the longer lines represent the migration of the sun god *kin* to his northern and southern extremities along the horizon. The entire diagram is reminiscent of the *kin* symbol (Fig. 61*a*, upper left), which probably derives its form from this concept.

Figs. 57*b* and *c* are quite similar even though they originated in different places. Fig. 57*b*, from the Codex Féjervary-Mayer, is Mixtec, about fifteenth century, while Fig. 57*c* is a Maya calendar in the Madrid Codex (pp. 75–76), written in Yucatán at about the same time.

Viewed both symbolically and functionally, the basic feature of the Féjervary diagram, which contains much the same information as the Madrid, is a floral symbol with two sets of four petals: a "Maltese Cross" with large trapezoidal petals and a "St. Andrew's Cross," or floral pattern consisting of four smaller rounded petals positioned at 45° angles between those of the Maltese Cross. A square design forms the center of the pattern.

The border of the entire design is marked with circles whose count totals 260. The ritual count is divided into cycles of 20 named days, counted in groups of 13. The first set of 13 commences with 1 Cipactli (alligator) whose teeth are visible just above the upper right-hand corner of the central square. Moving counterclockwise along the border, we proceed to count 12 blue dots (shown on a dark field in the figure) completing the count of 13 on 1 Océlotl (jaguar). (The reader might like to follow the sequence by employing Table 15.) The third cycle passes across the top of the diagram ending on 1 Mázatl (deer), and we continue the pattern with counts of 13 terminating on Xóchitl (flower), Acatl (reed) (symbolized on the back of the bird in the upper-left corner), Miquiztli (death), Quiáhuatl (rain), Malinalli (grass), Cóatl (serpent), Técpatl (flint knife), Ozomatli (monkey), Cuetzpallin (lizard), Ollin (movement), Itzcuintli (dog), Calli (house), Cozcacuauhtli (buzzard), Atl (water), Ehécatl (wind), Cuauhtli (eagle), Tochtl (rabbit), and finally returning to 1 Cipactli to close the ritual count. Since all these symbols are pictured at the vertices of the double-cross design, the 260-day cycle is made to encapsulate all other astrological and calendrical matters depicted within the diagram.

The five regions of the world along with their associated colors are enshrined in the four arms of the Maltese Cross and at the center: the four cardinal points (crossarms) and the zenith (center). We have east (red) at the top, west (blue) at the bottom, north (yellow) to the left, and south (green) to the right. When the sun rises, he sees the north to his right, the south to his left; straight ahead is the region of the west where he will die each night.¹⁰ In this depiction the sun is represented by a spiked disk in the eastern arm of the Maltese Cross, while the death head is pendent below the central square. The four arms of the St. Andrew's Cross signify the four houses of the sun in the sky, two in the east and two in the west. These are the intercardinal points symbolizing the extremes to which the sun will migrate along the horizon during the course of the year. Thus, we have summer solstice sunrise at the upper left, winter solstice sunrise at the upper right, summer sol-

Table 16. *Information Contained in the Calendar on Page 1 of the Codex Féjervary-Mayer*

<i>Direction</i>	<i>Petal</i>	<i>Year Bearer</i>	<i>Named Days</i>	<i>Staff</i>	<i>Bodily Part</i>
East	Upper left	Acatl	Atl, Ollin, Cóatl, Acatl, Cipactli	Guacamaya plant	Hand
North	Lower left	Tecpatl	Ehécatl, Itzcuintli, Técpatl, Miquiztli, Océlotl	Fruit tree	Foot
West	Lower right	Calli	Cuauhtli, Calli, Ozomatli, Quiáhuitl, Mázatl	Cactus plant	Throat
South	Upper right	Tochtli	Tochtli, Cozcacuauhtli, Malinalli, Cuetzpallin, Xóchitl	Maize plant	Head

<i>Direction</i>	<i>Tree or Plant</i>	<i>Source</i>	<i>Bird</i>	<i>Color</i>	<i>Ritual Subject</i>
East	Blue or turquoise tree	Sun	Quetzal	Red	Solar
North	Cactus	Incense	Eagle	Yellow	Autosacrifice
West	Maize	Death skull	Blue-colored bird	Blue	Dead woman
South	Cacao	Serpent Tlaltecuhтли (earth god)	Parrot	Green	Earth

stice sunset at the lower left, and winter solstice sunset at the lower right. We may consider the zenith position (center) as the sun's fifth house.

Within each quadrant signifying a cardinal direction, one finds a representative tree, a source for the tree, a bird, and a directional ritual (see Table 16 for details).

Xiuhtecuhtli, the celestial fire god, is located at the center. He is armed with spears and an *atlatl* (a spear thrower) and toward him flow four streams of blood. He is the first of Nine Lords of the Night. The remaining Eight Lords are pictured, two to each flap of the Maltese Cross as follows:

2. Iztli (east, right)—flint knife
3. Pilcintecuhtli (east, left)—young maize
4. Cinteotl (south, right)—maize
5. Mictlantecuhtli (south, left)—death
6. Chalchiuhtlicue (west, right)—jade skirt, water (female)
7. Tlazoltéotl (west, left)—earth, cleanser of the soul (female)
8. Tepeyollotl (north, right)—heart of the hill
9. Tláloc (north, left)—rain

Elements pertaining to the cardinal directions can be found in the petals of the St. Andrew's Cross. These include a ritual plant within

and a representative bird at the tip of the petal. Table 16 summarizes the vast quantity of symbolic information derived from this single page of the Codex.

Of great importance is the year bearer borne on the back of each bird. In four of the interstices between the petals appear the five named days which pertain to the given direction. In the remaining spaces between petals flow the rivers of sacrificial blood emanating from different parts of the human anatomy, each having been assigned a direction in space.

To use the calendar to tally the count of the 365-day year, we begin in the east with 1 Acatl, the name associated with New Year's Day for that year and, consequently, the day which brings in or bears that year. Counting through the cycle of 20 day names 18 times, we are left with a remainder of 5 days; thus, using Table 16, we arrive at the name of the day bearing the second year: Tecpatl. Likewise, New Year's Day of the third year bears the name Calli and that of the fourth year, Tochtli. The fifth year begins on the same day as the first, Acatl (since $365 \times 4 = 1,460$ and $1,460 \div 20$ gives a remainder of zero), and we close the cycle.

The postconquest calendar of Fig. 57*d* is intended to tally a single 52-year cycle which is broken down into four groups of 13 years, each branch emanating toward a cardinal direction, then turning to pass along the horizon. The open arms at the end of the cruciform design form a swastikalike pattern. Names of successive New Year's days in the cycle begin at the top (east) with 1 Acatl (*cañas* = reeds), then pass to the left to 2 Tecpatl (*pedernales* = flint knives), 3 Calli (*casas* = houses), 4 Tochtli (*conejos* = rabbits), 5 Acatl, 6 Tecpatl, 7 Calli, and so on, opening spirally in a counterclockwise sense.

In this synthesis of the calendar, we see an attempt by the keepers of Mesoamerican time cycles to unite various symbols within a cosmological framework. For each direction in the Féjervary diagram, we have a color, bird, planet, and so on—even parts of the body seek a spatial cosmological interpretation.

Of interest to the astronomer is the fact that many diagrams embody both the 260-day ritual count and the solar-based 365-day year (in the form of a count of days as well as in the incorporation of the oscillatory annual movement of the sun along the horizon). The theme seems to be the unification of the two counts, a matching or fitting of the ritual and vague year cycles. Unfortunately, we have little information on how this task was actually accomplished from observations of the heavens. A spatiotemporal unification is also exemplified in calendrical diagrams by the use of year bearers for directions, the allocation of each named day to a zone along the horizon, and the counting of 260 days along the perimeter of the world.

EXERCISES IN CALENDAR MECHANICS

In order to become more familiar with the operation of the Calendar Round let us employ an example to illustrate its operation. Suppose we have the complete Calendar Round date 8 Chicchan 15 Tzec. Con-

sulting our two calendar wheels (or Table 15), we see that the next day would be 9 Cimi 16 Tzec, written



This would be followed by 10 Manik 17 Tzec. Now, where will the next 15 Tzec date occur in the 260-day cycle? Counting 365 days after 8 Chicchan, we proceed through one full turn of the calendar wheel of Fig. 54 and are left with a remainder of 105 days. Finding 8 Chicchan on the wheel and proceeding forward 105 days, we come to 9 Oc (numbered 230), which is our answer. The next 15 Tzec date will be 10 Men; and the following, 11 Ahau. We discover a very useful theorem in Maya calendrics: given a position in the 260-day cycle, in each succeeding vague year the day number will advance by 1 and the day position by 5. This happens because 365 is divisible by 13 with a remainder of 1 and by 20 with a remainder of 5.

The vague year of 365 days differs from the tropical year, or the year of the seasons, by .2422 days. This means that if the vernal equinox occurs on 0 Pop this year it will occur on 1 Pop four years hence and around 4 Uo one hundred years later. Therefore, the Maya year count will slide gradually out of phase with the seasons, completing a full run through the seasonal year in 29 Calendar Rounds of 52 vague years or 1,508 vague years (1,507 tropical years). It is not known for certain whether the Maya recognized such a cycle, though Lounsbury (1978, p. 807) regards it as quite plausible. The calendric record they left implies that they were concerned primarily with keeping the count of elapsed days regardless of the seasons. But we must be careful not to conclude from this that the vague year calendar bore no relation to celestial events. As we shall see later, there may have been a cosmic connection.

Armed with this new information let us now return to the Leyden Plate (Fig. 52) and extract a complete Initial Series date. We recall that glyph blocks 2 through 6 gave the Long Count date 8.14.3.1.12. For the smaller glyphs at the bottom we shall call row A that to the left and B that to the right as is the usual custom among Maya epigraphers.

Glyph 7 may be recognized as a modified form of the Eb day glyph (see Fig. 53; the arced lines in the upper-right corner are a dead giveaway). This glyph is preceded by a single dot and thus should be read 1 Eb. Glyph A9 resembles our Yaxkin month glyphs (Fig. 55); it has no number preceding it. Therefore, the complete Initial Series date must be 8.14.3.1.12 1 Eb 0 Yaxkin. We note that the inscribed date indicates the seating of a new month as well as a new cycle of 13 day numbers. Had the Leyden Plate been dated one kin later, the inscription would read 8.14.3.1.13 2 Ben 1 Yaxkin; a kin earlier would give 8.14.3.1.11 13 Chuen 19 Xul.

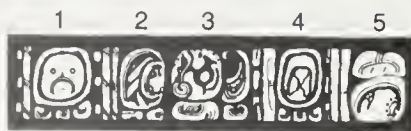
Let us use the deciphered Leyden Plate Initial Series date to derive the Calendar Round position of the zero date of the Maya Long Count.¹¹ Using Table 14 we see that 8.14.3.1.12 represents 1,253,912 days elapsed since 0.0.0.0.0.¹² We know that the 1 in 1 Eb is repeated every thirteenth position in the day number count and the Eb is repeated every twentieth. If we divide 1,253,912 by 13 we get a remainder of 10; there-

fore, day zero must have been assigned that number which came 10 digits before number 1 in the 13 count; this is the number 4. Dividing 1,253,912 by 20 we get 12 for a remainder. Counting backward 12 units from Eb in the table of 20 day names, we arrive at Ahau. Therefore, day zero in the 260-day cycle must have been 4 Ahau. Alternatively, we could have divided 1,253,912 by 260 (remainder 192) and used the 260-day calendar wheel of Fig. 54 to arrive at the same answer.

What was the position of zero day in the vague year? Division of 1,253,912 by 365 yields a remainder of 137 days. If we backtrack our way 137 days through the Haab wheel of Fig. 56, starting at 0 Yaxkin, we arrive at 8 Cumhu. Therefore, day 0.0.0.0.0 must have been 4 Ahau 8 Cumhu in the Calendar Round. This is a date well worth remembering, since it provides us with information which can assist in deciphering incomplete or effaced dates. For example, suppose the Long Count date 9.13.19.13.1 is the only portion of an Initial Series date which can be read on a monument. We can find the position in the Calendar Round quite easily. Using Table 14, we determine the elapsed count from zero to be 1,396,701 days. This is divisible by 260 with a remainder of 241 and by 365 with a remainder of 211. Again using our calendar wheels of Figs. 54 and 56 to count forward from 4 Ahau 8 Cumhu, we arrive at 11 Imix 14 Yax for the corresponding Calendar Round position.

As a further illustration of the interplay between Long Count and Calendar Round and of the power of our calculations, let us suppose we read a date with part of the Long Count missing, for example, x.12.6.5.8 3 Lamat 6 Zac, where x represents an effaced baktun. The historical record tells us that the most likely possibilities are x = 8, 9, or 10, but which is it? Only one of these three Long Counts can match 3 Lamat 6 Zac and we deduce that it must have 9 in the baktun position. We need not proceed very far to arrive at this result. Of the three possibilities, only the Long Count beginning with baktun 9 yields the required remainder of 12 when divided by 13 to obtain the day number. (These 12 days counted from the 4 in 4 Ahau give 3 Lamat.)

We have seen that given a Long Count date we can uniquely determine the position in the Calendar Round; however, the converse is not true since an enormous number of Long Count dates exist which would fit with 4 Ahau 8 Cumhu; in fact one of them occurs every 2.12.13.0 days. Frequently, particularly in Late Classic times, only Calendar Round dates were recorded in the inscriptions. For example, on the sarcophagus lid in the tomb beneath the Temple of the Inscriptions at Palenque we read (Lounsbury, 1974):



These can be identified as a pair of Calendar Round dates: 8 Ahau 13 Pop (1 and 2) and 6 Etz'nab 11 Yax (4 and 5).¹³ These dates mark the birth and death of Lord Shield Pacal, the occupant of the stone coffin and at one time ruler of Palenque. From other inscriptional evidence at Palenque, epigraphers discovered that the most likely pair of matching Long Count dates to fit the Calendar Round are 9.8.9.13.0 and

9.12.11.5.18. Pacal must have possessed a sturdy constitution to have lasted 4.1.12.18 days!

By the time of the Spanish conquest the Maya priests abbreviated the Calendar Round dates even further. We encounter readings like "katun ending 1 Ahau." Such scant information gives no knowledge of the katun to which reference is being made. The abandonment of the Long Count well before the arrival of the Spanish in the New World has greatly complicated the exact dating of many of the monuments.

John Teeple (1930), a chemical engineer who deciphered many of the Maya calendric inscriptions in his spare time, believed that the Maya astronomers, particularly those at Copán, had achieved such a degree of exactitude in correlating their calendar with the tropical year and lunar month by 9.17.0.0.0 that they no longer felt it necessary to record a complete date. By this time they had enough confidence in their expertise at calendar keeping to proceed with their calculations by using certain established Long Count dates to which they added small corrections expressed in terms of the Calendar Round dates. For example, in many of the prophetic books of Chilam Balam there occur such statements as "Katun 8 Ahau: Mayapan was depopulated" (Landa, 1941, p. 37n.). Mayapán, a Post-Classic capital of the Maya world, evidently suffered total devastation, as the condition of the ruins still reflects today.

Now, just when did all this misfortune occur? We know that Mayapán was founded shortly after the fall of Chichén Itzá (around A.D. 1275, or 11.3.0.0.0 in Maya). In fact, the ceremonial center was probably intended to replicate Chichén, complete with a Castillo and even a round Caracol tower (see Chapter V for the astroarchaeological details). Since the conquest took place about 11.15.0.0.0, the fall of Mayapán must have occurred between katuns 3 and 15 of the eleventh bak-tun. The painting of the aspect of the katun refers to the Maya habit of expressing the completion of such a period by writing zeros in the lowest three orders. Therefore, our date must be one of the katun ending series 11.4.0.0.0, 11.5.0.0.0, . . . 11.14.0.0.0. Furthermore, the statement also tells us that the matching position in the 260-day cycle must be 8 Ahau. Of course all the aforementioned Long Count dates will be Ahau dates since division by 20 gives a remainder of zero.

But a simple clue enables us to select the only correct date for the fall of the city: division of the Long Count by 13 must give a remainder of 4 since four days added to 4 Ahau give the required 8 Ahau. The only possibility fitting this criterion is 11.12.0.0.0 (A.D. 1441). The year 1441 is also fixed from the postconquest writings of chroniclers Landa, Cogolludo, and Villagutierre Soto-Mayor. The glory of Mayapán was indeed short-lived, marked by a century and a half of war and dissension.

THE SUPPLEMENTARY SERIES AND THE LUNAR SYNODIC MONTH

We have deciphered most of the inscription on the Leyden Plate (Fig. 52), but what of the rest of it? The material remaining in rows 8–11 following the Initial Series is called the Supplementary Series, or

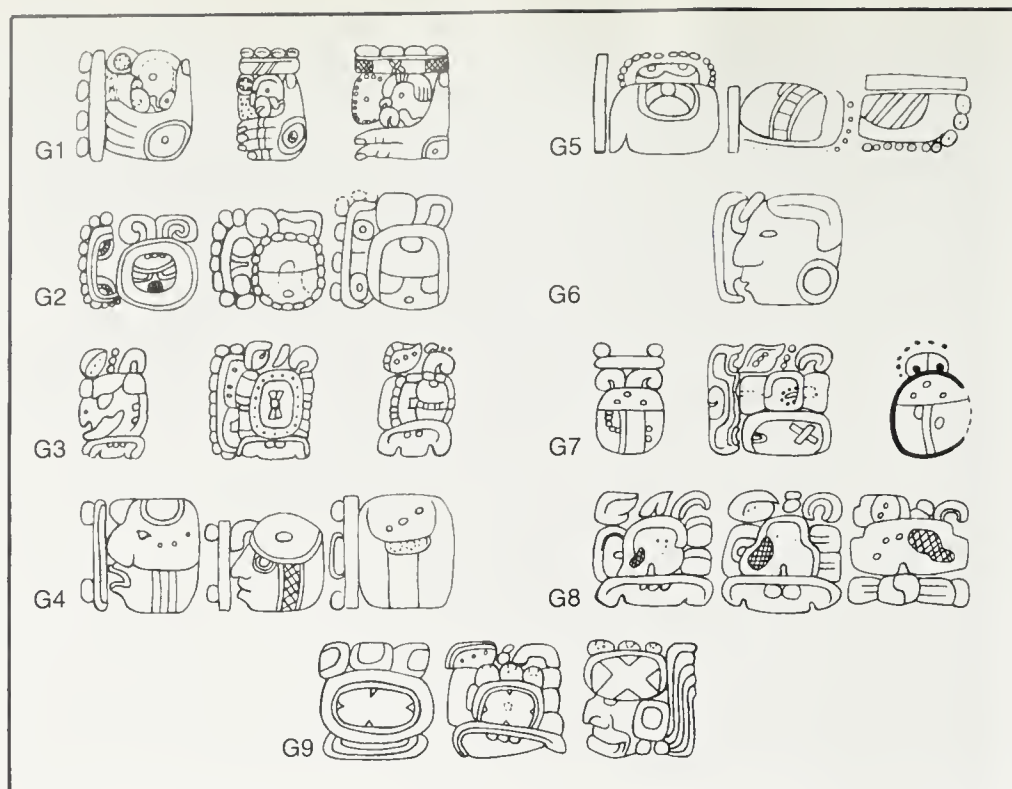


FIG. 58. Glyphs representing the Lords of the Night. (Diagram by P. Dunham)

Lunar Series, of glyphs because it is restricted almost completely to lunar information. From our discussion of its astronomical properties, we have already seen that the lunar motion is irregular and, consequently, difficult to predict. All the more reason for ancient astrologers to expend considerable efforts trying to understand how their primary female goddess coursed over the heavens. To further complicate decipherment, the glyphs of the Lunar Series also exhibit several variants. Below we give a brief account of the meaning of each, and in Figs. 58 and 59 we display a few representative forms. For a complete catalog of all forms which have been detected to date, the reader should consult Thompson's *Maya Hieroglyphic Writing* (1950).

Glyph G (Fig. 58). This glyph is decidedly nonlunar and has nine forms, each of which represents one of the Nine Lords of the Night. These lords follow in an endless cycle, each of them ruling for one night. Aztec history has preserved their names in Central Mexican mythology, as we discussed earlier. Some bring good fortune, others bad, to the night they rule. The system of alternating good and evil gods ruling specific time periods is similar to the ancient Babylonian astrological system of alternating good and bad planetary gods ruling successive hours of the day and night.

On the Leyden Plate (Fig. 52), block A8, the ruling lord is number 5, as may be seen by comparing that block with the forms of Glyph G5 shown in Fig. 58. This is the lord who ruled the night of 8.14.3.1.12 of the Long Count.¹⁴ The night of 8.14.3.1.13 would have been ruled by lord number 6, symbolized by Glyph G6. Glyph G5 would show up again on 8.14.3.2.1 and again on 8.14.3.2.10, or every nine days. A short

cut to determining the ruling Lord of the Night consists of dividing the sum of the lowest two places of the Long Count date by nine. The remainder is the number of the ruling lord. For example, in the case of the Leyden Plate, we have 1.12 or $32 \div 9 = 3$ with a remainder of 5, thus predicting form 5 of Glyph G. If there is no remainder, then number 9 is the ruling lord. Lord 9 is the one most frequently encountered in the inscriptions since he rules tun and katun ending dates, the anniversaries of which are often noted in the inscriptions.

Glyphs D and E (Fig. 59). These glyphs are used to indicate the age of the moon counted from the previous new moon for the indicated Long Count date. Glyph D is a compound usually consisting of a hand with the forefinger pointing to the right and/or a half-moon sign with three vertical dots. Interestingly, hand gestures are still used among contemporary Maya to indicate time periods (Neuenschwander, 1978). The glyph appears with coefficients from 0 to 19 and means that the moon age is less than 20 days. Glyph E, usually a single element, such as a stylized half moon, has coefficients 0 to 9 and means that the moon's age is over 20 days by an amount equal to the accompanying coefficient. When both D and E are present without coefficients, a new moon is implied. Thus,



, or 8D, means the age of the moon is 8 days, while



, or 3E, implies a 23-day-old moon. Often these signs represent an actual record of observed moon ages, for in many cases, given the proper correlation, they agree within a day or two of the actual moon age determined from modern astronomical calculations.

Glyph C (Fig. 59). This glyph possesses a form similar to D with a hand on the left, a half moon on the right, and often a small head in the upper left-hand corner. It counts the number of a particular lunation in a completed cycle of six moons (177 days), or a "lunar semester." Our discussion of eclipses in Chapter III suggests that Glyph C must have been of great importance to the Maya priests in eclipse calculations. We shall see evidence in the codices that the six-moon count was used precisely for this purpose. When Glyph C occurs, its accompanying coefficient is almost always two to six. If there is no coefficient, then the first moon in the cycle is indicated. Thus, 4C 8D means eight days after the fourth new moon in a cycle of six. It is still an open question whether this notation refers to current moons or elapsed moons. There is some evidence that in the so-called Period of Independence (about 9.5.0.0.0 to 9.12.0.0.0) different lunar numbering systems were kept among the Maya cities, one of them calling a particular moon the fifth in a cycle while another called it the fourth. The cities even may have competed with each other by trying to influence their neighbors to adopt their own particular lunar count.

Teeple (1930) has suggested that about 9.16.5.0.0 (A.D. 756) a fundamental change in the moon counting system occurred at Copán.

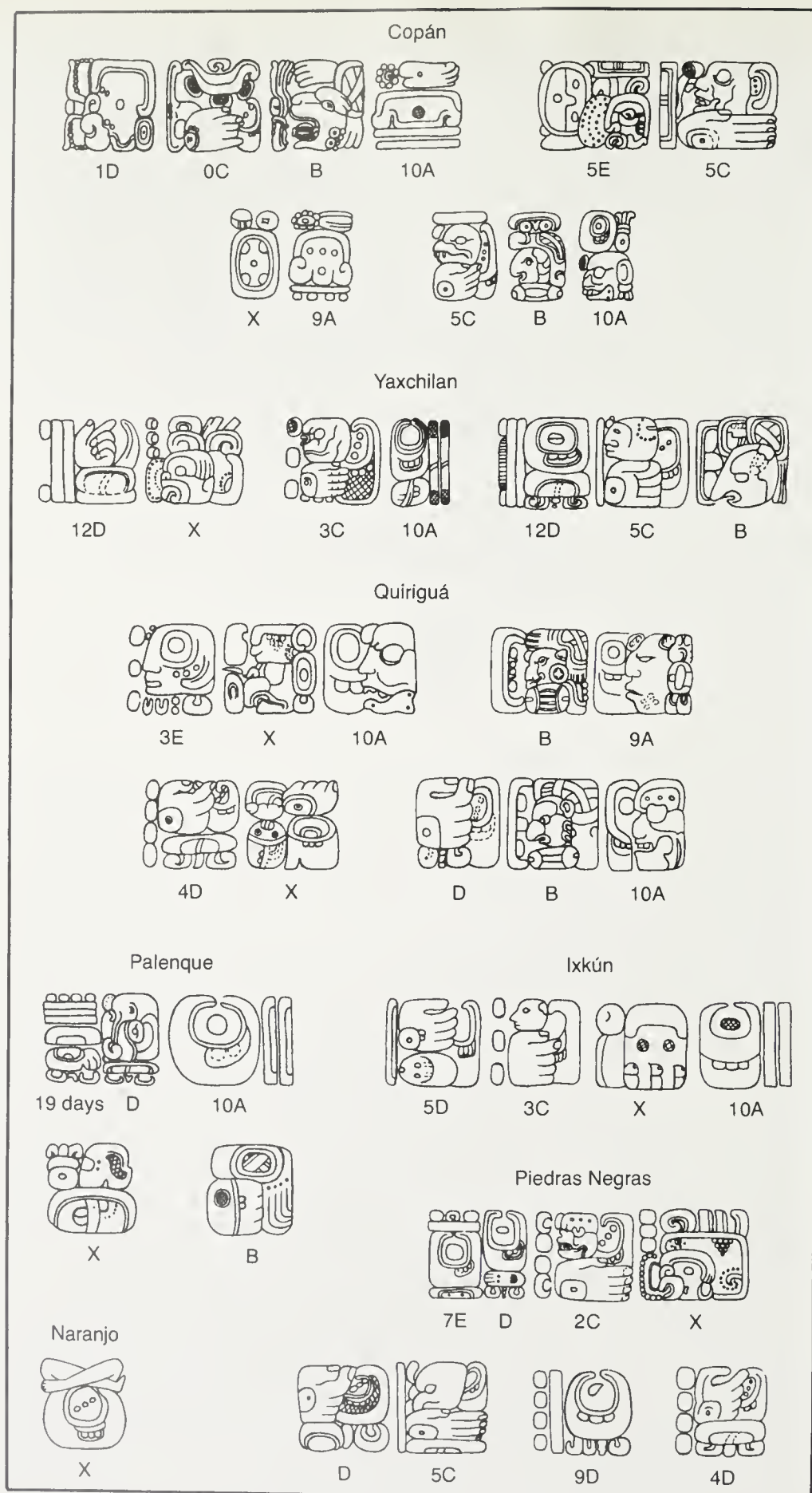


FIG. 59. A sampling of Supplementary Series inscriptions from monuments at various Maya ruins. (Diagram by P. Dunham)

Here the one-to-six lunar count was recommenced at an eclipse conjunction. On occasion it became a one-to-five count since the eclipse half year is shorter than six lunations (by about 4 days). There must have been a great convention at the "Copán Academy of Sciences," as Teeple calls it, at which the knowledge of the occurrence of eclipses was disseminated to form the new lunar count to be used throughout the empire. This would have been a great intellectual achievement for its time, but did Altar Q at Copán commemorate the event? It is a large block of stone with sides decorated by sixteen carved human figures (astronomers?), each seated on a hieroglyph identifying the city he represented. Two figures, larger than all the rest, confront each other in conversation. A glyphic text on the top of the altar bears the date 9.17.5.0.0 (A.D. 776). We know that a series of important meetings took place at Copán about this time, but researchers have been unable to tell us with any certainty whether the subject matter being discussed by the men pictured on Altar Q was astronomical, astrological, religious, or perhaps even political. The fact remains that Copán's monuments seem to suggest that, perhaps along with Palenque, it was one of the two or three centers where detailed accurate astronomical calculations were performed.

Glyph X (Fig. 59). This glyph has numerous forms which change according to the coefficient of Glyph C. For example, when the coefficient of C is three, Glyph X often has the cross-legged form. Though its meaning is not completely understood, it probably possesses greater religious than astronomical significance.

Glyph B (Fig. 59). This glyph exhibits only a few forms: usually a sky sign with elbow shape or an animal (dog?) head. It may refer to the house or constellation in the sky in which the moon resided.

Glyph A (Fig. 59). Since a ten or nine coefficient always accompanies this moon glyph, its meaning has been taken to indicate whether the completed lunation referred to was of 29 or 30 days' duration. We might well expect the Maya, who shunned irrational numbers, to record lunar synodic periods this way. Since the synodic period of the moon is $29\frac{1}{2}$ days, there will be three 29-day moons and three 30-day moons counted in each cycle of six if only whole numbers are used. When Glyph C has an odd coefficient, Glyph A usually shows 30 days, and when the coefficient of C is even, A shows 29 days. This regularity suggests that the current moon length is being recorded.

Other glyphs of the Supplementary Series represent dawn (Glyph Y) and night (Glyph Z), as well as the last day of the moon. They are all rather rare in occurrence and little is actually known about the details of how they function.

I invite the reader to summarize the discussion of the basic elements of a Maya date by interpreting the calendrical inscriptions shown in Fig. 60. You may use the glyphic forms exemplified in Figs. 53, 55, 58, and 59 to identify each component of a given date. It is also instructive to calculate whether the inscribed Calendar Round and Supplementary Series are consistent with the Long Count tabulated. Correct solutions are given in the figure captions.

By a combination of careful visual observation and laborious record keeping in stone and manuscript, the Maya were able to determine

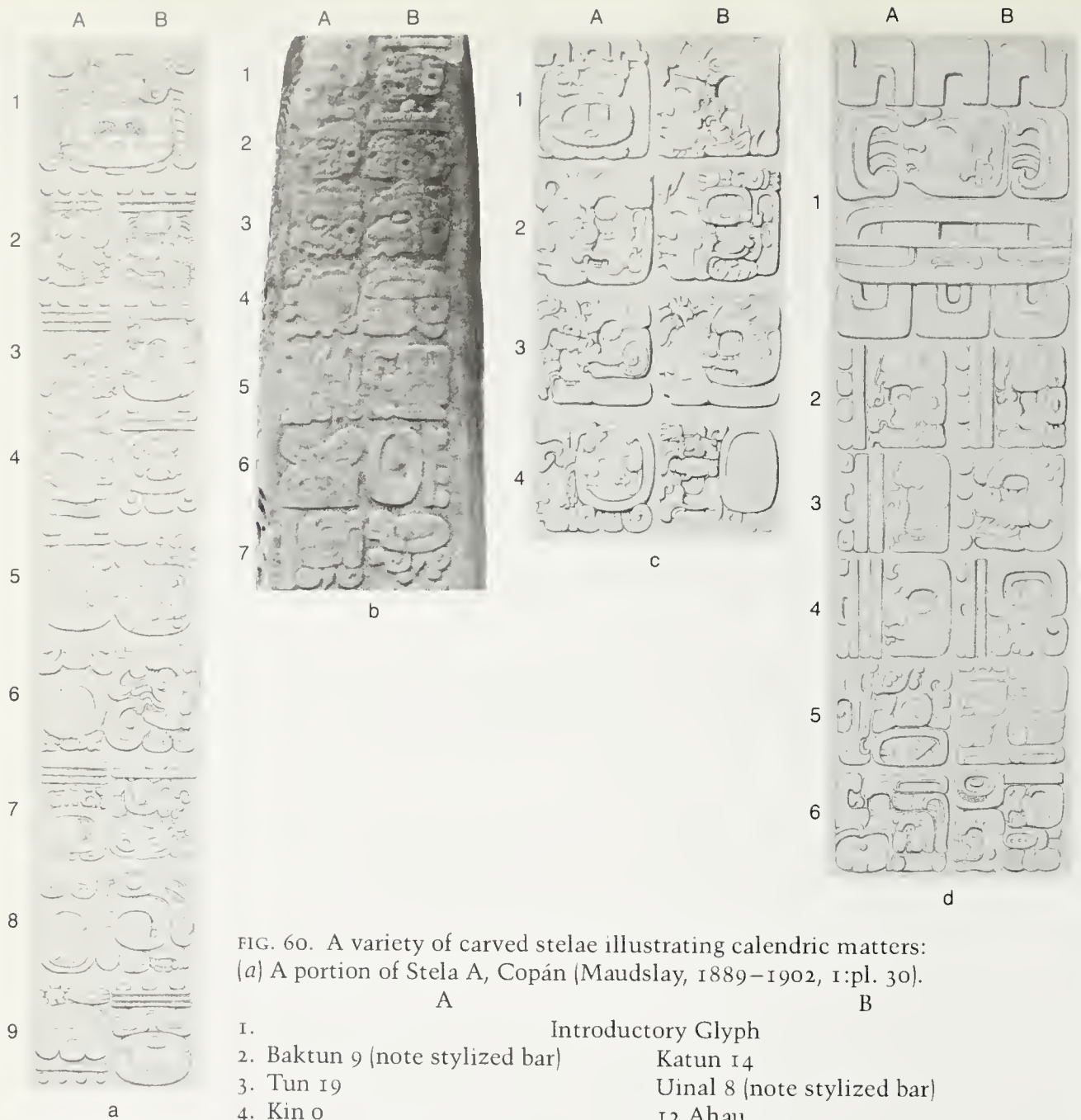


FIG. 60. A variety of carved stelae illustrating calendric matters:
(a) A portion of Stela A, Copán (Maudslay, 1889–1902, 1:pl. 30).

- | A | B |
|--|--|
| 1. Introductory Glyph | |
| 2. Baktun 9 (note stylized bar) | Katun 14 |
| 3. Tun 19 | Uinal 8 (note stylized bar) |
| 4. Kin 0 | 12 Ahau |
| 5. Lord of Night G7 | Nonastronomical |
| 6. Nonastronomical | Nonastronomical |
| 7. 15D; the age of the moon is 15 days | 6C; this is the sixth moon in the current cycle |
| 8. X; the name of current moon is? | B; the celestial house in which this moon is located is named? |
| 9. 9A; this moon is of 29 days' duration | 18 Cumhu |

(b) A portion of Stela 3, Tikal.

- | A | B |
|----------------------------------|------------------|
| 1. Introduction (partly effaced) | Baktun 9 |
| 2. Katun 2 | Tun 13 |
| 3. Uinal 0 | Kin 0 |
| 4. 4 Ahau | Lord of Night G9 |
| 5. 17D | B |
| 6. X | 9A |
| 7. 13 Kayab | Noncalendric |



e

(c) Stairway of Palace House C, Palenque (Maudslay, 1889–1902, 4:pl. 23). Only the Initial Series is shown. Here the numerals appear in head-variant form.

A	B
1. Introductory	Baktun 9
2. Katun 8	Tun 9
3. Uinal 13	Kin 0
4. 8 Ahau	13 Pop

(d) Stela E (west side), Quiriguá (Maudslay, 1889–1902, 2:pl. 31).

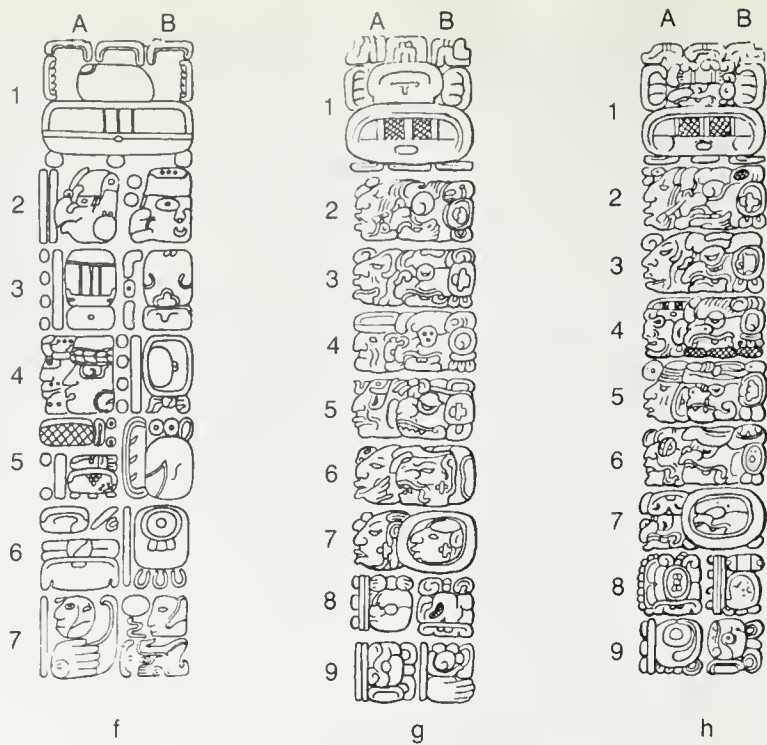
A	B
1.	Introductory
2. Baktun 9	Katun 14
3. Tun 12*	Uinal 4
4. Kin 17	12 Caban
5. G7 (modified by another glyph at the upper right)	7D 3C (upper portion only)
6. XB	10A (head-variant numeral, left side only)

*The scribe has made an error. As the reader can show, the Long Count is not consistent with the given Calendar Round position. The intended entry was probably 13; that is, a dot has been left out.

(e) Ballcourt marker, Chinkultic (from a rubbing, or *copa de molde*, by Nicolette, 1971).

Clockwise, from the top

1. Introductory	7. 11 Ix
2. Baktun 9	8. G2
3. Katun 7	9. Unidentified
4. Tun 17	10. 7 Zotz
5. Uinal 12	11. 4E (head-variant form of numeral)
6. Kin 14	12. Unidentified



(f) Lintel of the Initial Series, Chichén Itzá (Morley, 1915, fig. 75b).

A	B
1.	Introductory
2. Baktun 10	Katun 2
3. Tun 9	Uinal 1
4. Kin 9 (head-variant form)	9 Muluc
5. 7 Zac	G2
6. F (rare form not discussed in text)	5D
7. 5C	5X/B

(g) Temple of the Foliated Cross, Palenque (Morley, 1915, pl. 12a). As in FIG. 60h, this date must refer to an occurrence in the very distant past (Baktun 1).

A	B
1.	Introductory
2.	Baktun 1
3.	Katun 18
4.	Tun 5
5.	Uinal 4
6.	Kin 0
7.	1 Ahau
8. 13 Mac	G8
9. 10D	5C

(h) Temple of the Sun, Palenque (Morley, 1915, pl. 12b).

A	B
1.	Introductory
2.	Baktun 1
3.	Katun 18
4.	Tun 5
5.	Uinal 3
6.	Kin 6
7.	13 Cimi
8. G3	19 Cch
9. 8E	D

certain fundamental astronomical periods with remarkable accuracy. Among these periods were the lunar synodic month, the length of the tropical year, and certain eclipse cycles. But how were these achievements actually accomplished? As we answer this question, the information content of the Maya astronomical glyphs begins to take on greater significance.

For the Maya, the moon was the wife of the sun, possibly two goddesses, one representing the waxing and the other the waning moon as so frequently pictured in the codices. The Lunar Series portion of a Maya date suggests that the moon phases were of particular importance to the priest-astronomers. We do not know for sure whether they counted lunations from full moon or from the first visible thin crescent moon in the west after sunset (probably the latter), but surely the accuracy that the Maya achieved in determining the lunar synodic period must be attributed to a long-term averaging process. To illustrate, suppose a full moon occurs on January 25 of this year and I observe the next full moon on February 24. From two simple observations I can say that I have determined the lunar synodic period to be 30 days. But anyone who has looked at the full moon will realize that the precise instant of full phase cannot be determined accurately by visual observation. Even a telescope provides little help on this problem. Another observer, agreeing with my first observation, might say the second moon was closer to full phase on the twenty-third of February. His determination of the lunation period would be 29 days, equally as distant from the true period as my determination.

Now suppose that a count of days is kept along with a tally of full moons and next year at this time I find the twelfth full moon in the series to occur on January 13. Since this is 353 days after the first observation, I would conclude that the lunation period, based on a dozen observations extending over a year, is $353 \text{ days} \div 12 \text{ lunations}$, or 29.417 days per lunation. My friend might record full moon number twelve on January 14. His result, therefore, gives $354 \text{ days} \div 12 \text{ lunations}$ or 29.500 days for the period. Both answers are quite close to 29.53059 days, the true period measured by modern astronomers who study the lunar motion. A longer observing time base yields a more accurate result. Immediately we can see the significance of Glyph A in the determination of the length of the synodic month over a long period of time.

At Palenque several complete dates, including both a Long Count and lunar information from the Supplementary Series, are connected by the formula $81 \text{ moons} = 6.11.12$. This gives a lunar period of 29.53086, which lies within one-thousandth of 1 percent of the modern value, an error of about 23 seconds in one lunation! At Copán the lunar equation $149 \text{ moons} = 12.4.0$ was used, giving a slightly less accurate result: one lunation = 29.53020 days. The latter system operated for a long time after 9.13.0.0.0 (the so-called Uniformity Period in the counting of lunations) in a widespread area about Copán. It strongly suggests that that city, considered to be the intellectual capital of the Maya world at the time, had a strong influence on date-recording techniques in neighboring centers. Earlier, in the Period of Independence (before 9.12.0.0.0), each city kept its own lunar calendar. Still later, in the Period of Revolt (after 9.16.0.0.0), some cities mysteriously reverted to the Palenque

moon formula, suggesting strong competition between the two centers.¹⁵

That the lunar calendar was geared to the tropical year is indicated by an examination of the coefficients of Glyph C. During the Uniformity Period, these coefficients are predictable for any Maya center which adopted the system; that is, the priests seem to have intended groupings of six lunations to fall at specific positions in the yearly calendar throughout all Maya territory. Apparently, this system dissolved about 9.16.5.0.0 when Copán began to insert an occasional five-moon cycle (148 days) into the lunar calendar. As we shall see, this is identical to the type of notation employed in the eclipse tables in the Dresden Codex and it suggests that once again Copán astronomers were leading the way.

TROPICAL YEAR CALCULATIONS

Considerable architectural evidence is presented in Chapter V which suggests that the people of Mesoamerica were concerned with permanently fixing the rise-set positions of the sun on particular calendar dates. We know they could have determined the length of the year with considerable accuracy using only a pair of sticks to mark the positions of the sun on the horizon. Yet the calendar has been characterized as a time machine which indiscriminately cranks out one day at a time in endless progression. True, the vague year is a close approximation to the year of the seasons, but the slippage between the two is pretty large, amounting to about one-fourth day a year. Thus, if Christmas day, defined by a particular sun-at-horizon position, occurs on 12 Kayab during the current vague year, it will occur on 13 Kayab four years from now and on 14 Kayab eight years from now. If, on the other hand, I identify Christmas with 12 Kayab always, in a few centuries I will be forced to celebrate it in a different season of the year. A "white Christmas" would become a thing of the past. In fifteen centuries Christmas would have progressed all the way through the tropical year, returning close to mid-winter once again.

It seems strange to the Western mind that the Maya, who were so attuned to astronomical periods, would fail to record the $365\frac{1}{4}$ -day tropical year, instead favoring the 365-day vague year, which is so discordant with the laws of nature. Is there any calendric evidence to suggest that the Maya were interested in the tropical year? According to Teeple (1930), a lunar count may have been employed to keep track of the tropical year. A possible solution comes from the reading of dates on the stelae at Copán as well as in the Dresden Codex. In a few places we find Long Count dates separated by 19.5.0, or 6,940 days. Nineteen tropical years by modern computation equals 6,939.6 days. More importantly, it also equals 235 lunations. This is the so-called Metonic cycle mentioned in Chapter III. It functioned to match the lunar phases to the year of the seasons. It tells us that, if a new moon occurs on George Washington's birthday in 1980, we can expect a new moon to recur on his birthday in 1999, nineteen tropical years later.

To give an example of how the lunar count may have been used to

keep track of the position of the tropical year within the vague year, let us look at Teeple's argument:

On Stela A at Copán, three dates appear:

(a) 9.14.19.8.0 12 Ahau 18 Cumhu

(b) 9.15.0.0.0 4 Ahau 13 Yax

(c) 9.14.19.5.0 4 Ahau 18 Muan

(B) is undoubtedly the most important date on the stela since it establishes the ending of a katun, an important event for the Maya priest. Date (c) occurs 19.5.0 after the beginning of the katun and suggests that a lunar count was used in the calculation. Then what about date (a)? We note that it occurs 200 days before the katun ending date, but what is its calendrical significance? Now, the advance of the tropical year of 365.2422 days over the vague year of 365 days turns out to be precisely 200 days measured from the zero date to 9.15.0.0.0. Apparently, the Maya wanted to know how much the true year slipped ahead of their vague year. According to Teeple (1930), the reasoning involved in the calculations probably proceeded as follows: Katun 15 is slightly in excess of 3,844 tropical years from zero date. This can be expressed as 202×19 years + 6 years, or 202×235 synodic months + 6 years. Utilizing the clue that a lunar phase count was used to keep track of the tropical year, we convert 202×235 moons = 47,470 moons into days using the Copán moon formula (149 moons = 4,400 days). Thus, 202×235 moons = 1,401,799 days. Adding 6 vague years counted by the day, we arrive at 1,403,990, which the Maya would regard as the date 9.14.19.17.10 7 Oc 3 Yax. Thus, the priest would have discovered that by 9.15.0.0.0 the original zero Calendar Round date of 4 Ahau 8 Cumhu had moved through the vague year calendar 930 days, or twice 365 days, with 200 days elapsed through the third circuit (since 3 Yax occurs 200 days after 8 Cumhu).

Next the priest asks, since katun 15 ends at 13 Yax, of what month position in the calendar at the time of the zero point will 13 Yax be the anniversary? Counting backward 200 days from 13 Yax, he finds the result to be 18 Cumhu. Thus,

$$\begin{array}{r} 9.15.0.0.0 \quad 4 \text{ Ahau } 13 \text{ Yax} \\ - \quad \quad \quad 10.0 \\ \hline 9.14.19.8.0 \quad 12 \text{ Ahau } 18 \text{ Cumhu,} \end{array}$$

which is date (a) on the stela.

Similarly, on the Hieroglyphic Stairway of Copán we learn that at 9.16.12.5.17 the tropical year had advanced 208 days from 10 Mol to 18 Cumhu, the latter having been selected since it ended katun 17. Thus, the Maya seemed to be asking the question: What day at the zero point of our calendar was where 18 Cumhu is now? The answer is 10 Mol in 9.16.12.5.17.

If Teeple's interpretation is correct, then the manner in which the Maya kept track of the tropical year within the vague year is similar to our method of adding leap years to our calendar to keep it in phase with the seasons. The observations for determining the tropical year must have been very accurate for they yield a result for its length which is quite remarkable. To illustrate: in our language the Maya knew about the advance of 930 days of the tropical over the vague year by 9.14.19.8.0

after the zero point. In other words, they determined that after 1,404,000 days (= 3,846.0273 vague years) the tropical year was 930 days (= 2.5479 vague years) ahead of the vague year count. This may be expressed by the equation

$$(3,846.0273 + 2.5479) \text{ vague years} = 3,846.0273 \text{ tropical years,}$$

or 1 tropical year = 1.0007 vague years = 365.2550 days, a difference of less than 20 minutes from our modern calculations.

Other similar computations at Copán carried out to a larger number of significant places reveal a Maya tropical year of 365.2420 days. This result is closer to the presently recognized tropical year of 365.2422 days (incorrect by about one day in 5,000 years) than the Julian calendar in use in the Western world at the time and as close as our modern Gregorian calendar system, which was initiated a thousand years after the Maya performed their calculations.

One of the most suggestive tropical year calculations occurs among dates inscribed on the Temples of the Cross, Foliated Cross, and Sun at Palenque. Here we find one series of emphasized dates centering on the start of the current Maya era and another group on 1.18.5.0.0 (see Figs. 60g and h). These are separated by about 755 years, the period during which a position in the tropical year would have marched half way through the vague year. Other dates on stelae at Copán, Palenque, Tikal, and Quiriguá, when counted from established bases, show intervals of one-fourth, one-half, and three-fourths of a tropical year but with so many dates to play with that critics often state it is difficult to know the extent to which chance coincidence is involved. Kelley and Kerr's (1974) recent compilation of inscribed dates which show twenty tropical year positions out of ninety-two items has helped to narrow the credibility gap considerably.

It is fair to point out that since the 1930s Teeple's interpretation of Maya tropical year calculations has been challenged; nevertheless, it is now generally accepted that the Maya employed tropical year calculations of the type indicated above. The thrust of the counterargument posits the idea that many of the events recorded on the stelae are of historical rather than purely astronomical origin. At Palenque, for example, a dynastic sequence has been worked out. A significant portion of the information comprising calendar dates at the other Maya cities may be concerned with dates of birth, accession, and death of rulers or conquests or pacts. But it now seems likely that the Maya altered certain important events as they wrote their history in order to force the chronology of human events to coincide with astronomical occurrences. For example, the accession of a ruler to a throne or the waging of war could be arranged for an auspicious time, or a man might attempt to fertilize several wives at a particular lucky point and the one who was fortunate enough to become pregnant might become the principal wife. Given the Maya view of astronomy as a study of the interaction between celestial gods whose activities greatly influenced human affairs, this sort of behavior ought not to be at all surprising. Recent advances in the decipherment of the hieroglyphs, particularly through the approaches of Kelley and Lounsbury, have added a new dimension to the study of Maya inscriptions which encompasses both the astronomical and the historical approach. Investigators have only begun to

explore the possible astronomical significance of Maya dates now known to have been of historic importance. Indeed, future studies in Maya epigraphy hold a great deal of promise.

ASTRONOMY IN THE MAYA CODICES, I: AN ECLIPSE TABLE

"We must face it: so far as ends are concerned Maya astronomy is astrology." Sir Eric Thompson's (1972a, p. 77) comment is based in part upon a careful examination of the astronomical tables and almanacs which appear in the surviving Maya codices. Though the principal thrust of these documents seems to have been divinatory, the Maya intellectual achievements evinced in these manuscripts are nevertheless impressive.

Let us analyze a text which corroborates Thompson's statement and, at the same time, illustrates the tight bond between ancient astrology and astronomy. The Dresden Codex, a Maya picture book produced in northern Yucatán about the eleventh century and uprooted in a German library eight centuries later, is probably a copy of another folded-screen document produced a few centuries earlier. It is one of but four surviving fragments of Maya books. Two others, the Paris and Madrid codices, also receiving their names from the European cities where they were recovered, probably were delivered by conquistadors to the enlightened European nobility as representative New World curiosities. All three documents are fashioned from the flattened bark of the wild ficus tree and are surfaced with lime to provide gloss. The glyphs are painted with a fine brush in vivid reds and blacks, while other figures are rendered in yellow and blue as well.

Fragments of a fourth document, the Grolier Codex (Coe 1973), have recently come to light, though its authenticity is still doubted in some quarters, possibly because it is not as Maya-looking as the other three. Michael Coe's radio carbon dating of a fragment of the parchment upon which it is written indicates that it is a twelfth-century document. A possible Venus calendar in the Grolier Codex will be discussed later in this chapter.

The Dresden, the most complete of the manuscripts, displays a series of 260-day almanacs in addition to several astronomical calculations. In particular, it contains rather precise information about the motion of the planet Venus and the occurrence of eclipses. We focus our attention on these pages of the Dresden because they illustrate best of all the Maya astronomer's keen awareness of the heavens. We will be concerned principally with questions relating to the level of astronomical achievement and the underlying observational basis for the astronomical portion of the tables. For an extended discussion of the full content and the detailed astrological and ritualistic meaning of the tables, the reader is referred to Thompson's *A Commentary on the Dresden Codex* (1972b). Some of the specific astronomical symbols referred to in the codices are pictured in Fig. 61.

Pages 51–53 of the Dresden, reproduced in Fig. 62a, represent part of a lunar table which extends as far as page 58 in the original document. In Fig. 62b we display a schematic layout of these pages, where

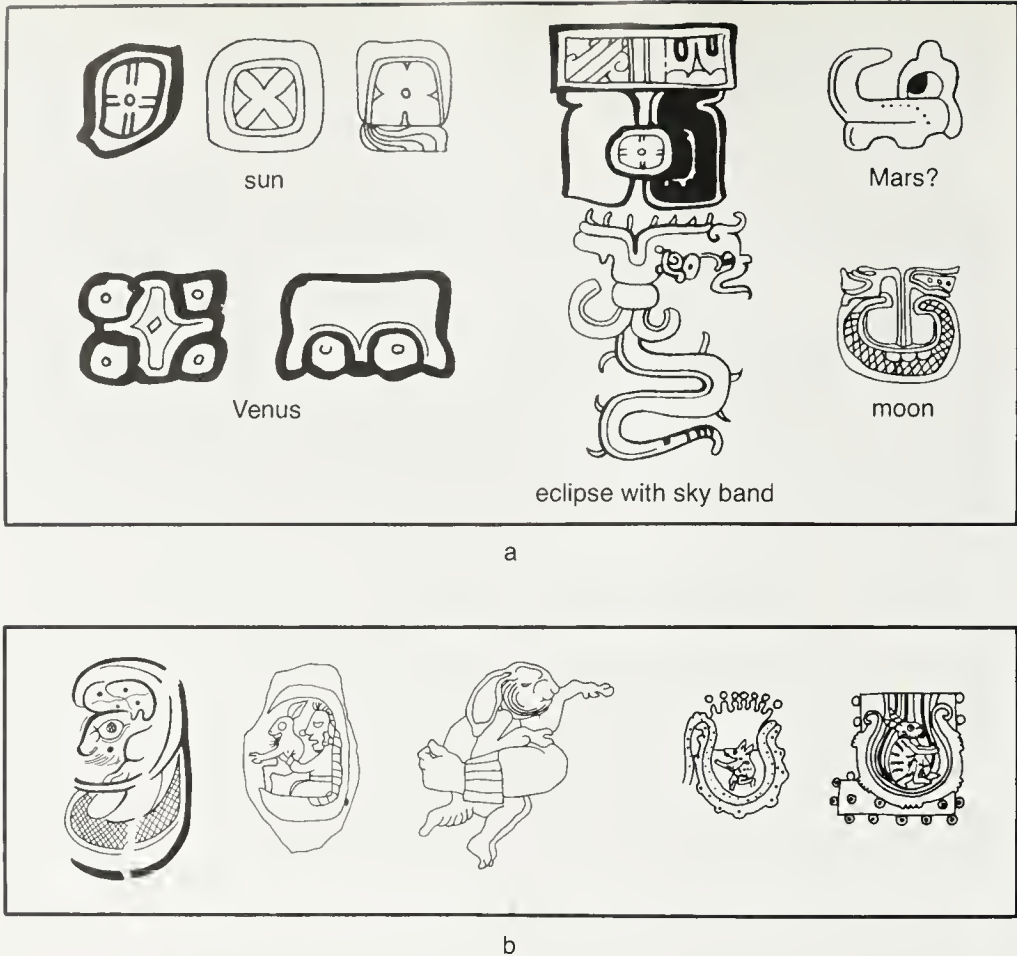
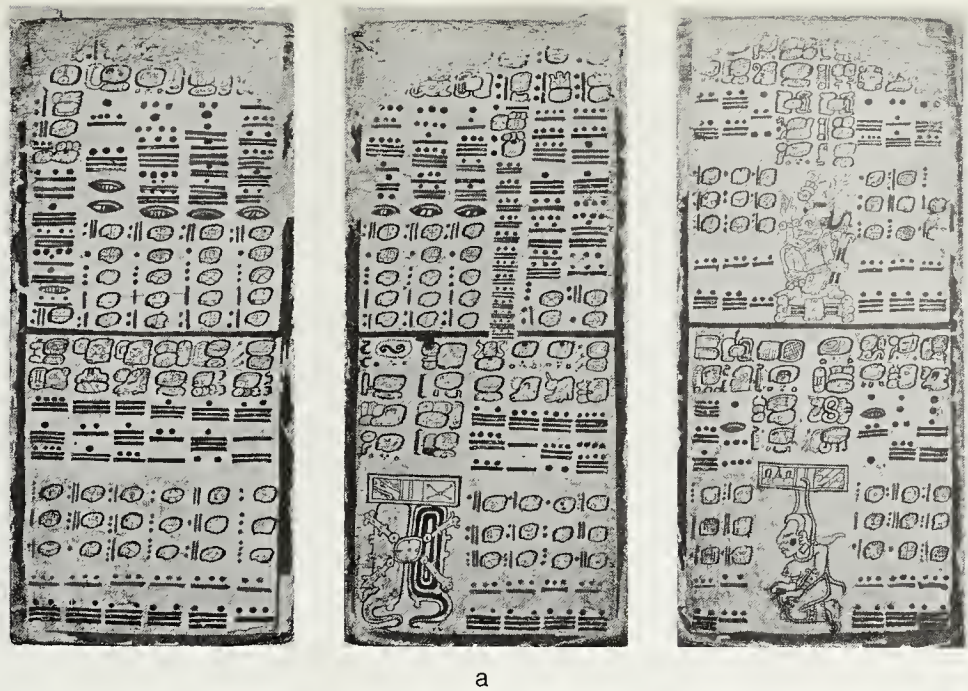


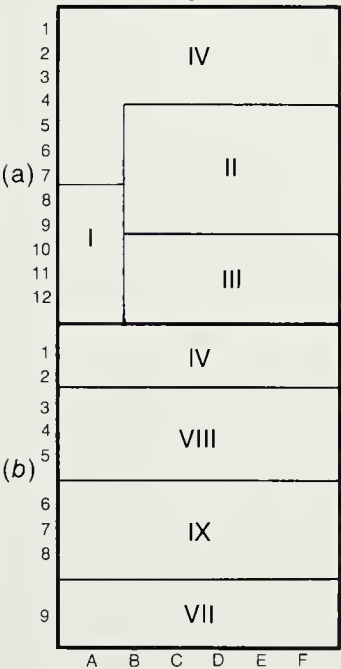
FIG. 61. (a) Some astronomically related hieroglyphs: assorted kin signs simultaneously symbolizing sun, day, and time (cf. FIG. 53e); Venus in the Dresden Codex; Mars beast and crescent moon from the Dresden; eclipse (also from the Dresden)—a dragon devours the sun (note kin sign), which lies against a black-and-white field hanging from constellation (?) bands (diagram by P. Dunham). (b) The first three figures depict the rabbit in the moon in Maya inscriptions (Schele, 1977, p. 55); the last two are from the Central Mexican codices (González Torres, 1975, p. 84; courtesy of SEP Setentas, Mexico City). See FIG. 27e for a view of the rabbit as it actually appears on the face of the moon.

we label the upper half of each page "a" and the lower half "b." The reading begins on page 51a and moves to the right to 52a, continuing to page 58a (not shown); then the reader shifts to the lower segment of the table back to 51b, proceeding to 52b, 53b, and so on, ending at 58b. We bypass pages 51a and 52a for the moment and examine one of the principal features of the table, which begins to make its appearance on page 53a. This property continues across the top halves of pages 54a–58a (not shown) and can also be seen in the few lower pages shown in Fig. 62. At the bottom of each half page, beginning with 53a row 9, we see the numeral 177 repeated a number of times (Block VII on Fig. 62b). This series always terminates with the number 148, after which a picture follows. For example, between pictures (Block VI) on pages 52b and 53b¹⁶ we find the number 177 written five times consecutively, followed by a 148.

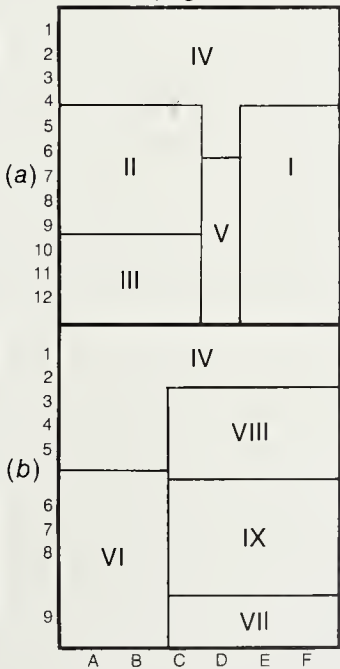


a

Instructions and Correction Table
page 51



page 52



b

Begin Table of Eclipses
page 53

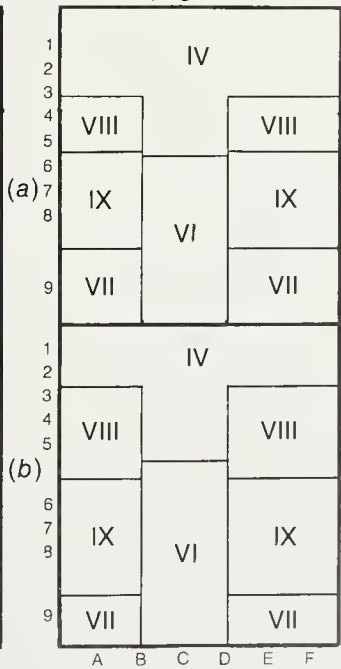


FIG. 62. (a) The Dresden Codex, pp. 51–53 (Thompson, 1972*b*; courtesy of American Philosophical Society, Philadelphia). (b) Schematic breakdown of the table:

A. Instructions and Correction Table

I. Initial Series dates

II. Multiples of the length of the table with corrections

III. Lubs

IV. Augural and other glyphs

B. Table of Eclipses (pp. 53*a*–58*a*, 51*b*–58*b*)

IV. Augural and other glyphs

VI. Eclipse picture

VII. 177- and 148-day intervals

VIII. Cumulatives

IX. Ritual (260-day) calendar dates

Table 17. *Intervals (Block VII) and Cumulatives (Block VIII) in the Eclipse Table of the Dresden Codex*

<i>Days Added</i>	<i>Totals</i>	<i>Days Added</i>	<i>Totals</i>
0	0	Picture	
177	177	178	6,408
177	354	177	6,585
148	502	177	6,762
Picture		177	6,939
177	679	177	7,116
177	856	148	7,264
177	1,033	Picture	
178	1,211	177	7,441
177	1,388	177	7,618
177	1,565	177	7,795
177	1,742	177	7,972
177	1,919	177	8,149
177	2,096	177	8,326
148	2,244	148	8,474
Picture		Picture	
178	2,422	177	8,651
177	2,599	177	8,828
177	2,776	178	9,006
177	2,953	177	9,183
177	3,130	177	9,360
148	3,278	177	9,537
Picture		177	9,714
177	3,455	177	9,891
177	3,632	148	10,039
177	3,809	Picture	
177 (178)	3,986	177	10,216
177	4,163	178	10,394
177	4,340	177	10,571
148	4,488	177	10,748
Picture		177	10,925
177	4,665	177	11,102
177	4,842	148	11,250
178	5,020	Picture	
177	5,197	177	11,427
177	5,374	177	11,604
177	5,551	177	11,781
177	5,728	177	11,958
177	5,905		
177	6,082		
148	6,230		

A few lines above these numbers in rows 3 to 5 we recognize another series of dot-bar numerals (Block VIII). Between the pictures on pages 52*b* and 53*b* are the numbers 6,408, 6,585, 6,762, 6,939, 7,116, and 7,264. It is easy to see that if we add the lower number of a given column to the upper number of the previous column we arrive at the upper number in the next column. Thus, $6,408 + 177 = 6,585$, and $7,116 + 148 = 7,264$; therefore, the upper numbers appear to be totals accumulated by repeated addition of the lower numbers.

To the attentive reader, two observations immediately should have suggested that these computations are related to eclipses: (a) the appearance in the table of the saros interval, 6,585, and (b) the near equivalence of 6 lunations and 177 days (actually 6 lunations = 177.18 days) and 5 lunations and 148 days (5 moons = 147.65 days). We might suspect from our discussion of eclipses in Chapter III that the number 177 is a very likely one to grace an eclipse table, for it lies close to the eclipse half year ($173\frac{1}{2}$ days).

In order to understand more specifically the connection of these numbers with eclipses, we lay out in Table 17 the full content of Blocks VII and VIII.

Note that occasionally a 178 is slipped into the summation column in place of a 177, although 177 is recorded at the bottom. Possibly, some sort of adjustment in the calculations was being made on these occasions. The usual count seems to have consisted of three moons of 29-day duration and three of 30 (see discussion of Glyph A earlier). Apparently, the 178-day count employed four moons of 30 days and two of 29, a move in the correct direction when we realize that the synodic month is slightly longer than $29\frac{1}{2}$ days. The intervals between the nine pictures are 1,742, 1,034, 1,210, 1,742, 1,034, 1,210, 1,565, and 1,211 days, all of which can be recognized as real eclipse cycles from our discussion of naked-eye astronomy (see especially Table 5). Finally, the total number of days in the table is 11,958 (about 33 years) or very nearly 405 moons ($405 \text{ moons} = 11,959.89 \text{ days}$). We recall that this is exactly the same moon count in use at Palenque ($5 \times 81 \text{ moons}$). Furthermore, this number is also commensurate with the 260-day cycle ($46 \times 260 = 11,960 \text{ days} = 405 \text{ moons}$); that is, it can be used to recover the same day of the Tzol kin with only a slight change in the phase of the moon.¹⁷ These conclusions lead us to a simple hypothesis: pages 51 to 58 of the Dresden Codex represent an eclipse table consisting of groups of five and six moons, the eclipses occurring at the positions of the pictures in the table. Since ritual calendar dates (Fig. 62*b*, Block IX) constitute the bulk of the table, the document may have been intended to record the dates of actual eclipses in the ritual calendar.

But is it a record of eclipses already witnessed or a document intended to warn of possible future eclipses? And what kind of eclipses? There seems little doubt that the Maya sought to predict eclipses because of the disaster which they believed threatened them on such occasions. The pictures of Block IV, for example, the pendent dead women and death god above her on page 53, are ominous enough. Of course, predictions must be based upon recorded observations of actual eclipses occurring in Yucatán when the Maya priests did their work. In order to explore how a table like that in the Dresden could have been

Table 18. *Intervals (in Days) between Lunar Eclipses Visible in Yucatán for the Period A.D. 400–500*

A.D. 400				
1048		354	178	355
S	1,920	178	176	325
872		856	680	354
	502	177	354	177
	177	1,034	177	177
	354	531	177	1,034
	178	339	503	A.D. 500
	1,211	S	176	
	176	341	178	
	680	354	177	
	1,211	354	162	
	176	1,034	S	177
	178	531	15	
	177	162		679
		S		1,211
162		502		
S	177	340		177
15		871		178
	679	S		176
	178	340		680
	354	532	14	
	679	162	S	177
	177	S	163	
	177	15		354
	176	177		178
		679		856
340		178		177
S	680	1,742		
340		502	871	
	177	531	S	1,565
			694	

Note: An "S" denotes an intervening solar eclipse.

fashioned from real observations, let us examine a series of actual eclipses, both solar and lunar, known from modern astronomical calculations to have occurred in ancient Yucatán. We will also attempt to determine whether such a tabulation can be used to predict future eclipses.

In Table 18 we list the day intervals between all lunar eclipses visible in northern Yucatán in the fifth century. There were seventy-three of them. We also insert the locations of the ten solar eclipses (S) visible with phase greater than 50 percent. Let us look at the lunar eclipses only, beginning with the interval separating the first two in the table, 1,920 days. Can we break this number down into a sum of 177's and a 148? We know that $10 \times 177 + 148 = 1,918$. If we add two more days to the total by twice substituting a 178 for a 177, we invent a series which bears a remarkable resemblance to that depicted in Block VII of the Dresden Table, for example, 177, 177, 178, 177, 177, 178, 177, 177, 177, 177, 148, eclipse. The next interval in Table 17, 502 days, is the sum of

Table 19. *Intervals (in Days) between Actual Fifth-Century Lunar Eclipses Expressed as a Series of Five- and Six-Moon Intervals*

A.D. 400						
177	177	178	Eclipse	177	176	177
177	177	148	177	177	Eclipse	177
178	178	Eclipse	177	177	178	177
177	177	177	178	178	Eclipse	177
177	177	Eclipse	177	177	177	148
178	177	177	177	177	Eclipse	Eclipse
177	148	177	148	177	177	177
177	Eclipse	Eclipse	Eclipse	177	Eclipse	Eclipse
177	176	178	177	177	177	177
177	Eclipse	Eclipse	177	148	177	177
148	178	177	177	Eclipse	177	177
Eclipse	Eclipse	177	Eclipse	177	148	178
177	177	177	177	177	Eclipse	177
177	Eclipse	177	177	148	177	177
148	177	148	148	Eclipse	177	177
Eclipse	Eclipse	Eclipse	Eclipse	177	178	177
177	177	177	177	177	177	148
177	177	Eclipse	177	177	177	Eclipse
Eclipse	177	177	178	Eclipse	177	177
177	148	177	177	178	148	178
177	Eclipse	178	177	Eclipse	Eclipse	Eclipse
Eclipse	178	177	177	176	177	177
178	Eclipse	177	148	Eclipse	Eclipse	148
Eclipse	177	148	Eclipse	177	178	Eclipse
177	177	Eclipse	177	178	Eclipse	177
177	Eclipse	177	178	177	176	177
178	177	177	177	148	Eclipse	Eclipse
177	177	177	Eclipse	Eclipse	177	177
177	177	Eclipse	177	177	178	Eclipse
177	148	177	Eclipse	177	177	177
148	Eclipse	177	177	Eclipse	148	Eclipse
Eclipse	177	178	Eclipse	177	Eclipse	177
176	Eclipse	148	177	Eclipse	177	177
Eclipse	177	Eclipse	177	177	Eclipse	178
177	Eclipse	177	177	Eclipse	177	177
177	176	177	148	177	177	177
178	Eclipse	Eclipse	Eclipse	178	Eclipse	148
148	177	177	178	148	178	Eclipse
Eclipse	177	177	Eclipse	Eclipse	Eclipse	A.D. 500

177 + 177 + 148. Continuing in the same manner, we can transform the remaining lunar eclipse intervals of Table 18 into the series consisting of five- and six-synodic-month intervals depicted in Table 19.

Except for an occasional 176 and the occurrence of some eclipses without a 148-day interval immediately preceeding, Table 19 is virtually identical to the one recorded in the Dresden, pages 51–58.

Now, where do the solar eclipses fit in? They are mentioned together with lunar eclipses in other passages in the Dresden. Furthermore, the 148-day interval is precisely the one at which sun and moon eclipses may occur together during a sequence of lunations. If we include solar eclipses in the series, then our first number in Table 18, 1,920, is broken down into the sum of 1,048 and 872; that is, following the first lunar eclipse in the fifth century, a solar eclipse occurred after 1,048 days. It was followed 872 days later by a lunar eclipse. Neither of these numbers, nor *any* of the other solar-to-lunar and lunar-to-solar eclipse intervals in the table, can be fashioned from a chain of 177's and 148's. This suggests that the table, *as it reads*, neither predicts nor records both solar *and* lunar eclipses. On the other hand, the intervals between solar eclipses do turn out to be sums of a series of 177's and 148; thus, the table could have been used exclusively for solar eclipses.

We can form a series which includes both kinds of eclipses, for example,

177	15	Solar	Lunar	Lunar
Lunar	Lunar	177	148	etc.
148	177	148	15	
15	148	15	Solar	
Solar	15	Lunar	15	

As we have seen in our discussion of eclipse astronomy in Chapter III, consecutive new and full moons are often associated with eclipses; therefore, we are forced to introduce the 15-day interval between full and new moons into our hypothetical table. Curiously, this number can be deduced as the difference between pairs of Long Count dates at the top of page 52 (Block I) of the Dresden. We will discuss this matter below when we refer to the ritual calendar dates in the table.

Given that both sets of empirical eclipse data, lunar and solar, can be utilized to construct the lunar tables, the hypothesis that the lunar data were actually used seems much simpler. In the course of the thirty-three years spanned by the table, the number of such eclipses observable in Yucatán would have been significant enough to enable a single priest to draw up the table. If we assume that solar eclipses alone were used, we must extrapolate the base of observations backward many centuries in order to derive the relevant intervals.

We have seen that an eclipse table like that in the Dresden can be created quite easily from the observational data. But, can it be used to predict future eclipses? To answer this question some scholars have attempted to match the Dresden table, eclipse for eclipse, with the actual eclipse record running all the way from the pre-Christian era up to the Spanish conquest—all to no avail. In view of the unpredictability of weather conditions and the difficulty of viewing solar eclipses of less than 50 percent partiality, it may not be so surprising that this became a fruitless task. Or perhaps the scribe pictured only special eclipses.

Let us imagine how a priest (with a biased twentieth-century mind) might use the fifth-century table we developed to predict lunar eclipses. Based on a few decades of tabulated observations, he would have become aware that once a lunar eclipse occurs the odds are pretty good that another will happen after 177 days, give or take a day. Consulting Table 19, we find that this situation occurred 43 percent of the

time in Yucatán in the fifth century. When a lunar eclipse failed to occur in the table 177 days after a previous eclipse, there were eight occasions when one did occur after an additional 177- or 178-day period (totaling 354 or 355 days) and there was one occasion when an eclipse occurred after another 148-day period (total 502 or 503 days). These cases occurred for 12 percent of the seventy-five lunar eclipses observable in the fifth century. The same would be true for upcoming eclipses in the sixth century. We see that the priest can make a simple prediction, namely, that once an eclipse of the moon is observed a second eclipse will be visible on one of these dates in the immediate future: (a) 177 days, (b) 325 (177 + 148) days, or (c) 354 (177 + 177) days later. Our helpful table tells us that with only three warning dates the priest will be correct in his prediction more than half the time (about 55 %). This is not to imply that the table was used precisely in this manner. The example demonstrates that truly successful skywatchers can lay out a short-range eclipse warning system which will foretell when the time will be right for future eclipses. Then, based on what actually occurs, they can alter their predictions. The Dresden table suggests that the Maya priest used only sums of 177 and 148 to accomplish this feat. Indeed, he must have been surprised to discover that never will a lunar eclipse occur after an interval which does not involve these numbers. By extending his base of observations over a long period of time, the astronomer could soon anticipate the likelihood of a clustering of eclipses over a short duration or of long, dry periods without eclipses; for example, notice the crowding effect between the tenth and twenty-first and between the forty-second and sixty-fourth intervals in Table 19, where eclipses are separated by an unusually large number of short intervals. The record on pages 51–58 of the Dresden extends over thirty-three years, or about one-third the time base employed in Table 19. If this were the only eclipse table that the Maya produced we would be hard pressed to conclude they had the power to predict lunar eclipses with any certainty. But we view only a very small sample of what they actually wrote. Even with these few fragments, we develop a sense of appreciation for the acuity of the Maya priest-astronomer. The reduction of a complex cosmic cycle to a pair of numbers was a feat equivalent to those of Newton or Einstein and for its time must have represented a great triumph over the forces of nature.

There is far more information in the Dresden eclipse table worth examining. Let us look briefly at the ritual portion of pages 51–58. Between the day intervals of Block VII and the cumulative totals of Block VIII we find day signs related to the 260-day calendar. These are written three to each vertical column (Block IX). Given their central position and the large amount of space they occupy, we must regard these symbols as having been of great importance. We start with the dates in rows 6–8, page 53a. If we count forward 177 days from the date 12 Lamat (page 52a, 11F), we arrive at 7 Chicchan (page 53a, 7A). It is followed 177 days later by 2 Ik (7B), and the addition of another 177 days leads to 7 Oc (7C), and so on. These must be the dates in the Tzol kin on which the eclipse warnings occurred; the adjacent dates, rows 6 and 8, which differ from those in row 7 by ± 1 day, appear to have been intended as single day corrections. Noting the positions of the dates

recorded in line 7 on the 260-day calendar wheel (Fig. 54) we find, as did Teeple in 1930, that they fall into three small arcs evenly spaced about the wheel. Evidently, the Maya realized that only certain zones of the 260-day calendar wheel were vulnerable to eclipses. We might think of these short arcs of the wheel as eclipse warning zones. In light of our discussion about the possible origin of the 260-day calendar, it should not surprise us that eclipses would be found to occur in this pattern. We recall that the eclipse half year and the 260-day count fit neatly together:

$$3 \times 173.3 = 2 \times 260 = 520.$$

Thus, for every two rotations of the Tzol kin wheel we are likely to have had three lunar eclipses spaced two-thirds of a Tzol kin rotation apart. A fourth eclipse, should it occur, would take place at nearly the same point on the wheel as the first. (The ecliptic limits give us a slight variation.) If the Maya cared about the geometry of the nodes of the lunar orbit and enjoyed playing with fractions as well, they might have employed a $173\frac{1}{2}$ -day count. But unlike that of the astronomers of the Classical World, their orientation was temporal instead of spatial; thus, they adopted the more obvious lunar formula: 6 moons = 177 days. The addition of 177 days following an eclipse resulted in a slow advance through the eclipse warning zones on the calendar wheel. When it became necessary, the Maya priest substituted a five-moon interval of 148 days for a 177-day interval to correct this slippage. Apparently, the recovery of certain ritual calendar dates for eclipses was of paramount importance for the Maya.

The format of the opening pages of the table, pages 51a and 52a, differs substantially from that of the remainder of the eclipse table. A pair of Initial Series dates intertwined in red and black appears in column A of page 51a. Four more Initial Series dates in the ninth baktun complete the top of page 52 (columns E and F). These are labeled Block I in Fig. 62. One of them is counted from an epoch preceeding 0.0.0.0.0. The other is a current epoch late Initial Series date: 10.19.6.1.9, nearly five centuries after the derivation of the table; perhaps it signifies a later use of the same table.

Across the middle of both pages are multiples of 405 lunations (Block II), below each of which are five ritual calendar dates: 12 Lamat, 1 Akbal, 3 Eznab, 5 Ben, and 7 Lamat (Block III). These are the *lubs*, or resting points, of the table where the user could enter the 260-day cycle. The lub of the lunar ephemeris beginning at page 53a seems to be 12 Lamat, give or take a day, as was suggested earlier. The evidence in this block of the table strongly suggests that the manuscript could be recycled; thus, the other lubs listed on that page could be used as later or earlier entry points into the ritual count. Because of their prominent positions at the beginning of the table, these lubs must have been of primary importance to the Maya calendar keepers. The whole scheme once again emphasizes the Maya compulsion for cyclicity.

The four Initial Series dates appearing on page 52a (Block I) have been the subject of much discussion among students of Maya epigraphy. They are interwritten two to a column, one in red, the other in black:

(a)	9.16.4.10.8	(12 Lamat)	col. F (black)
(b)	9.16.4.11.3	(1 Akbal)	col. F (red)
(c)	9.16.4.10.18	(3 Etz'nab)	col. E (black)
(d)	9.19.8.7.8	(7 Lamat)	col. E (red)

Dates (c) and (d) are clearly in error. As written, the 9.16.4.10.18 date counted from the beginning of the present epoch would have to be a 9 Etz'nab. However, if we assume that the scribe had left out a dot in the second place, the 3 Etz'nab of the 260-day count matches the Long Count date (9.16.4.11.18). If Long Count date (d) is written correctly, then the ritual portion must be 8 Lamat and not 7.

Thompson (1972*b*) suggests that the scribe had actually intended to write a 12 Lamat date in this position (the intended Long Count being 9.19.7.7.8), but his eye was distracted by the row of 7 Lamats to the left. As a result, he committed an error by substituting a 7 for a 12.

Though date (d) is a dilemma, there is some order expressed in the others. We note that date (b) follows date (a) by 15 days and date (c) follows (b) by the same interval. These dates may mark an eclipse of the sun at new moon (a) followed by a lunar eclipse at the next full moon, then another solar eclipse at the following new moon. It is interesting to note that the five lubs on pages 51*a*–52*a* are also separated by 15-day intervals. Occasionally (four times during the fifth century), the full moon occurring immediately after an eclipse of the sun was itself eclipsed. On one occasion an eclipse of the sun occurred on the new moon following a lunar eclipse. Paired events like these occurring within the same lunar synodic month constituted a clear break in the smooth 177/148-day series, which may have necessitated an adjustment in the ritual calendar assignment. Apparently, the Maya priests were expressing these corrections through the Long Count, though at this stage the precise mechanism they employed still eludes us.

Of the other pair of intertwined Initial Series dates (appearing in column A of page 51*a*), one is a baktun 10 date, which again would seem to suggest that a later use of the original table was intended. It has been suggested that the other date is a lub far in the past.

The lunar table is a marvel of astronomical accuracy. Altogether it marks 405 lunations, equating that period with 11,958 days and yielding a synodic month of 29.52592 days (by our way of thinking), only seven minutes away from the modern value. Furthermore, the table is recyclable. To complicate matters, the ritual needs of the Maya forced them to incorporate the 260-day cycle into the table. The cycle of $46 \times 260 = 11,960$ days is an interval which lies remarkably close to fitting the table.¹⁸ Any such multiple of the sacred round would guarantee that, after each trip through the table, the user would return to its resting point. Paradoxically, this Maya ritualism, which acted as a complicating drag on the calendar, was also the driving force. If Maya religion had no astrological attachments, the astronomers would have had no motivation to attain such great heights. Though we cannot claim to grasp fully all the subtle refinements of these pages of the Dresden Codex, they nevertheless stand as strong testimony to the genius of the Maya priest-astronomer, in his attempt both to master one of the wonders of nature and to condense its complexities into so brief a space.

For the Maya the importance of Venus, above all planets, cannot be overstated. It was called *noh ek* (great star), *chac ek* (red star), *sastal ek* (bright star), and *xux ek* (wasp star). We recall some of the statements the early chroniclers made about the Indians' propensity for watching it. Mexican friar Motolinía tells us that "next to the sun they adored and made more sacrifices to this star than to any other celestial and terrestrial creature" (Nuttall, 1904, p. 498) and "they knew on what day it would appear again in the east after it had lost itself or disappeared in the west . . . ; they counted the days by this star and yielded reverence and offered sacrifices to it." Why all this attention? One look at our discussion of earth-based observations of Venus in Chapter III reveals its uniqueness. Besides Mercury it is the only bright planet that appears closely attached to and obviously influenced physically by the sun. Venus announces the sunrise in the morning or rises from the ashes of the deceased solar luminary as darkness approaches (Séjourné, 1976). Venus symbolism has been identified in all forms of inscriptions, including the texts, pottery, and stelae.¹⁹ But the crowning achievement of Maya Venus astronomy surely must reside in the Dresden Codex.

Thompson calls the Venus table on pages 24 and 46 to 50 of the Dresden Codex "a subtle and mechanically beautiful product of Maya mentality" (1972a, p. 62). However, he warns us that the general layout of these pages, as in the lunar table, proves that the Maya were not concerned with glorifying their own intellectual achievement and that they preferred to venerate their gods instead. A portion of this divinatory table (pages 24, 46, 47) is shown in Fig. 63a, the general layout of which is remarkably similar to the eclipse tables in Fig. 62a, as a comparison of the schematic diagrams Fig. 62b and Fig. 63b illustrates.²⁰ Its function was likely the same as well—to serve as a warning table for the apparitions of Venus. The opening page is a user's manual consisting principally of multiples of the length of the table and the Initial Series dates corresponding to the lub, or entry point into the table. The bulk of the remaining pages concern Venus ritual—a long chain of important dates in the 260-day calendar associated with the planet along with accompanying pictures. The intervals and their cumulatives appear in the lower and upper registers, respectively, as in the eclipse tables. The scenario is the same—a re-enactment of pages 51 to 58 but with a different character in the starring role.

We look first at pages 46 to 50 (pages 48 to 50 not shown). The four lower numbers (Block VII) are repeated identically on each of these pages. They read 236, 90, 250, and 8. A picture follows and then the same four numbers. The black dots and bars higher up on the page (Block VIII) give cumulative totals: 236, 326 (= 236 + 90), 576 (= 326 + 250), 584 (= 576 + 8), 820 (= 584 + 236), and so on. Around the turn of the century a German librarian, Ernst Förstemann (1901), recognized that the tabulated 584 days represent an excellent approximation to the average synodic period of Venus, which modern astronomers found to be 583.92 days (see Chapter III); accordingly, he hypothesized that these represent a Venus almanac. To aid this hypothesis, the middle pictures of the three on the right side of each page depict various



a

Instructions and Correction Table Begin Venus Table
page 24 page 46

page 47

1							II-5
2							
3							
4							
5							II-4
6							
7							
8							
9							
10							II-3
11							
12							
13							
14							II-2
15							
16							
17							
18							II-1
19							
20	III						
21							
22							
23							
24							
25							

1							IV
2							
3							
4							
5							
6							
7							VI-1
8							
9							
10							
11							
12							
13							IV
14							
15							
16							
17							VI-2
18							
19							
20							
21							
22							
23							
24							VI-3
25							

1							IV
2							
3							
4							
5							
6							
7							VI-1
8							
9							
10							
11							
12							IV
13							
14							
15							
16							
17							VI-2
18							
19							
20							
21							
22							
23							
24							VI-3
25							

b

FIG. 63. (a) The Dresden Codex, pp. 24, 46, 47 (Thompson, 1972*b*; courtesy of American Philosophical Society, Philadelphia). (b) Schematic breakdown of the table:

- A. Instructions and Correction Table

I. Initial Series dates with lub (III)

II. Multiples of length of table with corrections

III. Ring number

IV. Augural and other glyphs

B. Venus Table (pp. 46–50)

IV. Augural and other glyphs

VI. Venus pictures

i. Augury pertaining to Venus apparition
2. Venus at apparition spearing victim

3. Victim being speared

VII. Venus apparition and disappearance intervals

VIII. Cumulatives

IX. Ritual calendar dates

X. Venus symbols; directional and miscellaneous glyphs

aggressive representations of the Venus god, Kukulcan.²¹ He is shown (Block VI-2) spearing different victims who appear in the lower pictures (Block VI-3). The Maya believed that certain perils were related to the heliacal rising of Venus after inferior conjunction, a time when his bright rays pierced the atmosphere like arrows causing death, pestilence, and destruction. In the *Anales de Quauhtitlán* (translated by Seler), a colonial document from the Mexican highlands, we find specific statements about which class of people shall suffer wounds from the piercing rays of Venus, called Quetzalcóatl in the Central Mexican pantheon (the calendric dates may be recognized as Mexican from Table 15):

And as they (the ancients, the forefathers) learned.
When it appears (rises).
According to the sign, in which it (rises).
It strikes different classes of people with its rays.
Shoots them, casts its light upon them.
When it appears in the (first) sign, "1 alligator."
It shoots the old men and women.
Also in the (second) sign, "1 jaguar."
In the (third) sign, "1 stag."
In the (fourth) sign, "1 flower."
It shoots the little children.
And in the (fifth) sign, "1 reed."
It shoots the kings.
Also in the (sixth) sign, "1 death."
And in the (seventh) sign, "1 rain."
It shoots the rain.
It will not rain.
And in the (thirteenth) sign, "1 movement."
It shoots the youths and maidens.
And in the (seventeenth) sign, "1 water."
There is universal drought. (Seler, 1904c, pp. 384–385)

There seems to be no doubt that unlucky days were associated with the heliacal rise of Venus, each to be regarded with appropriate ritual. The uppermost picture in each case (Block VI-1) refers to some sort of augury which attends each heliacal event.

Can we use the numbers contained in these pages to chart Venus' movement? The Venus synodic period is represented five times over on pages 46–50. Followed through once, the table is usable for a total of $5 \times 584 \text{ days} = 2,920 \text{ days}$, or exactly 8 vague years (7.995 tropical years).

On each page the Venus period is split into four intervals (Block VII), probably intended to correspond to (a) visibility as morning star (236 days), (b) invisibility at superior conjunction (90 days), (c) visibility as evening star (250 days), and (d) invisibility at inferior conjunction (8 days).²²

Referring to our astronomical discussion of the apparent motion of Venus, we note that only one of the intervals stated in the Dresden approximates reality: the 8-day disappearance at sunset. Interestingly enough, this is also the only Venus interval for which any direct liter-

any documentation exists. A passage in the *Anales de Quauhtitlán* tells us that “at the time when the planet was visible in the sky (as evening star) Quetzalcoatl died. And when Quetzalcoatl was dead he was not seen for 4 days; they say that then he dwelt in the underworld, and for 4 more days he was bone (that is, he was emaciated, he was weak); not until 8 days had passed did the great star appear; that is, as the morning star. They said that then Quetzalcoatl ascended the throne as god” (Seler, 1904c, pp. 364–365).

Sahagún is more specific about the reappearance of Venus. He tells us that when it appears in the east it makes four starts, shining only a little on its first three but on the fourth coming out with all its brilliancy and proceeding on its course.

It is puzzling that the 90-day interval in the table is so different from the true disappearance interval (about 50 days) and that the morning and evening star intervals are represented as being unequal.²³ Were the Maya priests who drew up the table deliberately attempting to emphasize the ritualistic or astrological importance of the planet rather than the accurate astronomical observations which surely they must have made in composing the rest of the table?

The ritualistic significance of pages 46–50 is stressed, as is the case for pages 51–58, by the abundance of ritual calendar dates which dominate most of the remainder of the table. We look at these next with the help of Table 20, which translates part of them.

Lines 1–13 (Block IX) give dates in the Calendar Round of the various “stations,” or apparitions, of Venus. Their reading begins with a heliacal rising at 1 Ahau, which terminates the table (page 50, column D, line 13—not shown), and moves us back to the beginning (page 46, A1), thence proceeding toward the right as shown in Table 20 (the first few lines have been effaced in the original document). Like the eclipse table in the same document, the Venus table can be recycled. Thus, the last heliacal rise terminating the table occurred on the lub 1 Ahau. After a 236-day appearance as morning star, Venus vanished behind the sun on day 3 Cib. It was lost from view for 90 days and returned as evening star on 2 Cimi, remaining in the western sky after sunset for 250 days. The 8-day disappearance commenced at 5 Cib and was followed by another heliacal rise on 13 Kan and so forth. This series terminates at page 50, line D13, with 1 Ahau. If we add 236 to this date, we return to 3 Cib and the table can be reused as it stands.

Page 24 of the Dresden²⁴ is to the Venus table what the tops of pages 51 and 52 are to the eclipse table. It contains information which fixes the starting point of the Venus ephemeris in terms of both the lub of the ritual calendar and the Initial Series. It also incorporates a multiplication table to aid the priest who wishes to recycle the table.

Since pages 46–50, when read through a single line in the ritual calendar, are valid for 2,920 days of Venus observations, we might anticipate that a useful table in the introductory page would consist of multiples of this number. This is exactly what we find in Block II of Fig. 63b. Starting at the lower right-hand corner of page 24 and proceeding to the left, we read for Block II-1:

Col. G	8.2.0	= 1 × 2,920	=	2,920	8 Ahau ²⁵
Col. F	16.4.0	= 2 × 2,920	=	5,840	4 Ahau

Table 20. *Scheme of the Ritual Calendar Portion (Block IX) of the Venus Table in the Dresden Codex*

Operation	Line	46A	46B
1 Ahau + 236 = (50D, 113)	1	3 Cib (+ 90 =)	2 Cimi (+ 250 =)
9 Ahau + 236 = (50D, 11)	2	11 Cib (+ 90 =)	10 Cimi (+ 250 =)
4 Ahau + 236 = (50D, 12)	3	6 Cib (+ 90 =)	5 Cimi (+ 250 =)
12 Ahau	4		
7 Ahau	5		
2 Ahau	6	↓	↓
↓	7	all Cib	all Cimi
	8	days	days
	9	↓	↓
↓	10		
	11		
	12		
6 Ahau + 236 = (50D, 112)	13	8 Cib (+ 90 =)	7 Cimi (+ 250 =)

Col. E 1.4.6.0 = 3 × 2,920 = 8,760 12 Ahau

Col. D 1.12.8.0 = 4 × 2,920 = 11,680 7 Ahau

Shifting to Block II-2, above, we continue the series with the fifth through the eighth multiples of 2,920: G. 14,600, F. 17,520, E. 20,440, D. 23,660. Above these, in Block II-3, we find the ninth through the twelfth multiples: 26,280, 29,200, 32,120, 35,040. If we add one more 2,920 to the last number, we arrive at a number representing thirteen trips through the table, or 37,960. Since the Venus 584-day cycle and the 260-day calendar are related by the equation

$146 \times 260 = 65 \times 584 = 37,960 \text{ days} = 5.5.8.0,$

we can expect a Venus station, for example, a heliacal rising, to repeat on a given Calendar Round date after this length of time. This interval also turns out to be 104 vague years, or two complete Calendar Rounds. Since the priests sought to relate astronomical cycles to the ritual calendar, they must have been extremely pleased to find this additional commensurability in their calculations.

Now, the next series of numbers (Block II-4)²⁶ on page 24 is peculiar:

Col. G 1.6.0.0 1 Ahau = 9,360 days = 16 Venus revolutions (of 584 days) plus 16 days

Col. F 4.12.8.0 1 Ahau = 33,280 days = 57 Venus revolutions minus 8 days

46C	46D	47A	47B	50D
5 Cib (+ 8 =)	13 Kan (+ 236 =)	2 Ahau (+ 90 =)	1 Oc etc.→	9 Ahau
13 Cib (+ 8 =)	8 Kan (+ 236 =)	10 Ahau (+ 90 =)	9 Oc etc.→	4 Ahau
8 Cib (+ 8 =)	3 Kan (+ 236 =)	5 Ahau (+ 90 =)	4 Oc etc.→	12 Ahau
↓ all Cib days ↓	↓ all Kan days ↓	↓ all Ahau days ↓	↓ all Oc days ↓	↓ all Ahau days ↓
10 Cib (+ 8 =)	5 Kan (+ 236 =)	7 Ahau (+ 90 =)	6 Oc etc.→	1 Ahau

Col. E 9.11.7.0 1 Ahau = 68,900 days = 118 Venus revolutions minus
12 days (= 61
VR - 4d + 57
VR - 8d)

Col. D 1.5.14.4.0 1 Ahau = 185,120 days = 317 Venus revolutions minus 8
days

Teeple (1930) suggested that these numbers were intended to bring the table into line with actual Venus observations. We note that sixty-five true Venus revolutions (each averaging 583.92 days) are closer to 37,955 days than 37,960 days, the intended length of the table. Thus, after two Calendar Rounds, a slippage of 5 days would occur between the actual timing of the heliacal rising of the planet and that predicted in the table. But the priest could have made use of these numbers to repair the table in a most ingenious way.

One of the lub's of the table was 1 Ahau (18 Kayab). This appears on the Initial Series starting date in column C, lines 19-20, of page 24. It is from this point (page 50, column D, lines 13 and 20) that one begins to reckon a new cycle. Recovery of the 1 Ahau lub must have been extremely important. Thus, the priest needed to find a way to force the Venus heliacal rise to occur on that date in succeeding cycles. How could this be accomplished? Taking the 1 Ahau 18 Kayab and adding the "peculiar number" 4.12.8.0 = 57 Venus revolutions less 8 days, he could reach a Calendar Round date of 1 Ahau 18 Uo, recovering the lub and at the same time assessing a partial correction to the Venus table.

Thus:

$$\begin{aligned} 57 \text{ true Venus revolutions} &= 33,283.4 \text{ days (observations)} \\ 57 \times 584 &= 33,288.0 \text{ days (table, uncorrected)} \\ 57 \times 584 \text{ less 8 days} &= 33,280.0 \text{ days (table, corrected)} \end{aligned}$$

Now this correction actually causes the table to drop a few days behind the true observations; that is, it is an overcorrection.

But, according to Thompson (1972a), this was only a part of the correction program. On the next four cycles through the table, the priest subtracted 4 days at the end of the sixty-first Venus revolution (only multiples of four could be used to recover the all important 1 Ahau lub date). Thus, imagine that the priest starts at the second cycle through the table with 1 Ahau 13 Mac (page 50, column D, lines 13 and 14). He counts 61 revolutions, ending at 5 Kan 7 Xul (page 46, column D, lines 13 and 14); subtracts 4 days, thus arriving at 1 Ahau 3 Xul (page 50, column D, lines 13 and 24); and returns to the start of the table for cycle 3. According to Thompson (1972a, p. 63),²⁷ the complete recipe for correcting the table was as follows: On the first cycle through the table, stop at revolution 57 and subtract 8 days. Then return to the beginning of the table. On the second, third, fourth, and fifth cycles, stop at revolution 61 and subtract 4 days, returning each time to the beginning of the table. Thus, after 301 (= 57 + 61 + 61 + 61 + 61) Venus revolutions, 24 days would have been subtracted. Now, 301×584 less 24 days is 175,760 days, and 301 true Venus revolutions is 175,759.92 days. The corrected Venus ephemeris places us within two hours of the true position of Venus on the sky after 301 Venus revolutions (481 years)! With such a set of corrections the table could have been used indefinitely. The achievement of this kind of accuracy by the Maya priest-astronomers is truly extraordinary.

Yet the behavior of the Maya priest in the performance of his Venus calculations seems paradoxical. Both modern and ancient astronomers know that, while the Venus year averages 583.92 days, a given year period can be as long as 587 days and as short as 581. Therefore, fluctuations between the table and the observations could have varied by a few days on many occasions. In spite of the seriousness with which the priests tallied the long-term average of their observations, the table gives no evidence that they paid any attention to short-term deviations. To the modern mind this seems baffling, but evidently it did not bother the Maya. They seemed to be willing to falsify their short-term planetary observations in order to make the planetary motion fit the ritual calendar. We can think of their short-term calculations as mean motions. Their tables became true astronomical ephemerides only when considered over long intervals.

Following the idea that Maya astronomical knowledge may be hidden within a ritual complex, Sharon Gibbs (1977) has elaborated a scheme which suggests how the Maya priests may have distorted their Venus observations to fit the ritual calendar, thereby resulting in the unnatural-looking Venus intervals which appear in the table. She notes that the ritual portion of the table consists of five named days—Kan, Lamat, Eb, Cib, and Ahau—and five more days exactly midway between them—Cimi, Oc, Ix, Etz'nab, and Ik. Regardless of the reasons for their selection, these must have been the dates to which the priests were compelled to refer the Venus observations in the table for the pur-

pose of staging the religious ceremonies and enunciating the prognostications that would have attended the Venus appearance and disappearance. Gibbs has shown that the intervals given in the table are precisely those which fall closest to the actual observation of Venus disappearance and reappearance while still permitting the official observation of these events to take place on the assigned days of the 260-day calendar. Such an argument is quite sensible in view of Tedlock's (1979) revelation that the contemporary Quiché Maya still use their 260-day calendar in exactly the same way, associating certain named days with favorable or unfavorable prognostications. The celebration of actual Venus observations on special named days that may not necessarily coincide with the actual event is rather like our custom of officially assigning certain holidays (Memorial Day, Lincoln's birthday, etc.) to the Monday of the week in which they occur.

Like Gibbs', Yale linguist Floyd Lounsbury's (1978) approach to assessing the corrections to the Venus table rests on the hypothesis that the Maya priests who designed it sought foreshortenings of only that magnitude necessary to locate another 1 Ahau date in the table which at the same time could accommodate observational error in the heliacal rise of Venus. The sanctity of the date, he tells us, was preserved because "One-Ahau" was the name of the great figure in Maya mythology who represented Venus. Lounsbury finds optimum intervals among combinations of the three Calendar Round base dates written in the table (1 Ahau 13 Mac, 1 Ahau 18 Kayab, and 1 Ahau 3 Xul), thus deducing most of the quantities tabulated in Block II of the multiplication table on page 24. His analysis, far too detailed to report in these pages, envelops many more visible aspects of the table than those of his predecessors and produces the same dramatic result in the realm of astronomical accuracy—that the Maya astronomers had succeeded in tabulating the motion of Venus to .08 part of a day in 481 years. Lounsbury's scheme also possesses the added advantage that many of the derived intervals in his correction program have the commensurability property so common among important Maya calendrical numbers.

On the lower-left portion of page 24 (Block I) we find a pair of Long Count dates (9.9.16.0.0 and 9.9.9.16.0). These provide us with some information about when the Venus table might have been used. The number 6.2.0 (Block III) also appears, tied in a bow to attract the eye. Because it is encircled, it has been called a "Ring Number." Usually a Ring Number is added to an earlier Long Count base date to give a later date. In this case, the intent was to add the Ring Number to a date prior to 0.0.0.0.0 4 Ahau 8 Cumhu in order to arrive at the latter date, the start of the present epoch. Thompson (1972*b*, p. 62) suggests that the addition might have proceeded as follows:

$$\begin{array}{rcl} 12.19.13.16.0 & 1 \text{ Ahau } 18 \text{ Kayab (previous epoch, not shown)} \\ + & 6. 2.0 & \\ \hline 0. 0. 0. 0.0 & 4 \text{ Ahau } 8 \text{ Cumhu (beginning of present epoch).} \end{array}$$

Then

$$\begin{array}{rcl} 12.19.13.16.0 & & \\ + & 9. 9.16. 0.0 & \\ \hline 9. 9. 9.16.0 & 1 \text{ Ahau } 18 \text{ Kayab (starting date of table).} \end{array}$$

The choice of this number of days after the zero date of the Long Count as the start of the table (at least four centuries before the surviving edition of the Dresden was written) may have been dictated by the fact that it is a whole multiple of 584, 365, and 260.

The number 9.9.16.0.0 (= 1,366,560) exhibits the remarkable capacity of being divisible by a wide range of important numbers in the Maya calendar, as Lounsbury has shown (1978). Thus,

9.9.16.0.0	=	260 × 5,256	(Tzol kin)
	=	365 × 3,744	(vague year)
	=	584 × 2,340	(Venus' synodic period)
	=	780 × 1,752	(triple Tzol kin or Mars' synodic period)
	=	2,920 × 468	(five times Venus' synodic period)
	=	18,980 × 72	(Calendar Round)
	=	37,960 × 36	(double Calendar Round)

For this reason he calls it the “super-number of the codex” (p. 787). Lounsbury has also illustrated that many Long Count numbers in the Dresden decompose into a large number of low prime factors. They seem to be “contrived” for use in the table because of their mathematical as well as their astronomical nature.²⁸

Only a few of the proposed correlations between the Maya and Christian calendars show a heliacal rising of Venus on the date 9.9.9.16.0 (e.g., the Smiley [1960] and Kreichgauer [1927] correlations; the GMT is off by 20 days). This ought not to shock us if we recall that the table needed to be corrected repeatedly by up to eight days at a time and that actual intervals between heliacal risings could deviate from the corrected mean by a few days. Nevertheless, the GMT correlation comes closest to fitting the astronomical facts.

If we apply the same program of corrections to Long Count dates as we did to ritual calendar dates, then we arrive at later Long Count starting dates for the table, which would have been useful to the priests who recopied the first edition (again the method is that of Thompson [1972*b*, p. 63]):

Initial starting date	9. 9. 9.16.0	1 Ahau 18 Kayab = February 5, 625
	+ 1. 6. 0.0	(the first peculiar number)
	<u>9.10.15.16.0</u>	1 Ahau 8 Zac
	+ 19.15.14.0	4 × 61 Venus revolutions
		minus 16 days
Starting date	10.10.11.12.0	1 Ahau 18 Kayab = October 24, 1039
	+ 4.12. 8.0	57 Venus revolutions minus 8 days
	<u>10.15. 4. 2.0</u>	1 Ahau 18 Uo
	+ 4. 8.17.0	61 Venus revolutions minus 4 days
Starting date	11. 0. 3. 1.0	1 Ahau 13 Mac = June 14, 1227
	+ 4. 8.17.0	61 Venus revolutions minus 4 days

If we employ the term 1.6.0.0 (instead of 1.5.5.0 as recorded in the table), then all starting dates correspond to Venus heliacal risings using the GMT correlation. All Long Count starting dates, regardless of which correlation is used, give the lub 1 Ahau.

We conclude our discussion of the Venus table in the Dresden Codex with a brief description of the remaining portions of the Venus table (principally from Block X). On pages 46–50:

Lines 14, 20, 24: These give alternate vague year positions which may be matched with the positions on the Tzol kin wheel given in lines 1–13 of the appropriate column. Thus, the full Calendar Round entry for page 46, column C, line 13, would be 10 Cib 19 Tzec, 10 Cib 4 Yax, or 10 Cib 14 Pax.

Lines 18 and 22: Förstemann (1901) named these repeated symbols and their variations the Venus glyph. They are often found in glyphic association with a sign interpreted to mean “red” (*chac* in Yucatec). The name *chac ek*, “red star,” is a common name for Venus throughout Mesoamerica. The same symbols are carved in stone, for example, on the Palace of the Governor at Uxmal and on Temple 22 at Copán, both of which exhibit Venus orientations (see Chapter V). However, Kelley (1976, p. 47) believes the sign simply connotes “star.”

Lines 16 and 23: World direction glyphs (north, south, east, west) repeated in varying order. Evidently successive apparitions of Venus were associated with different quarters of the horizon.

Line 17: Glyphs associated with various deities.

The remaining glyphs are of a literary nature and few have been interpreted.

Like the lunar table before it, the Venus table in the Dresden Codex represents a fusion of astrological and astronomical cycles. The quintuple Venus period of $13 \times 2,920$ days flashes out of the table as the perfect equivalent of 146 Tzol kin. At the same time the vague year and Calendar Round are worked in. According to Lounsbury (1978) and Smiley (1973),²⁹ even the lunar cycle may have been forced on the scene. The puzzling 236- and 250-day falsified apparitions of Venus correspond to 8 and $8\frac{1}{2}$ lunations, respectively. The use of mathematically contrived numbers that Lounsbury emphasized in his recent study of the Dresden suggests that the Maya appreciation of number transcended even astronomical principles.

The discovery of a fourth Maya codex was announced at a meeting of the Grolier Club in New York in April 1971. It appears to have weathered the test of several years of questioning relating to its authenticity. The background and arguments concerning the originality of the document are fully laid out in *The Maya Scribe and His World* by Michael Coe (1973). Given the sparsity of pre-Columbian documents, if it is the fourth Maya Codex to come to light, then its content is of great significance, especially in the realm of Maya astronomy, for it appears to be part of a Venus calendar.

Our view of a segment of the surviving 12-page fragments (Fig. 64) reveals its Maya-Toltec nature not only in the characteristic positions

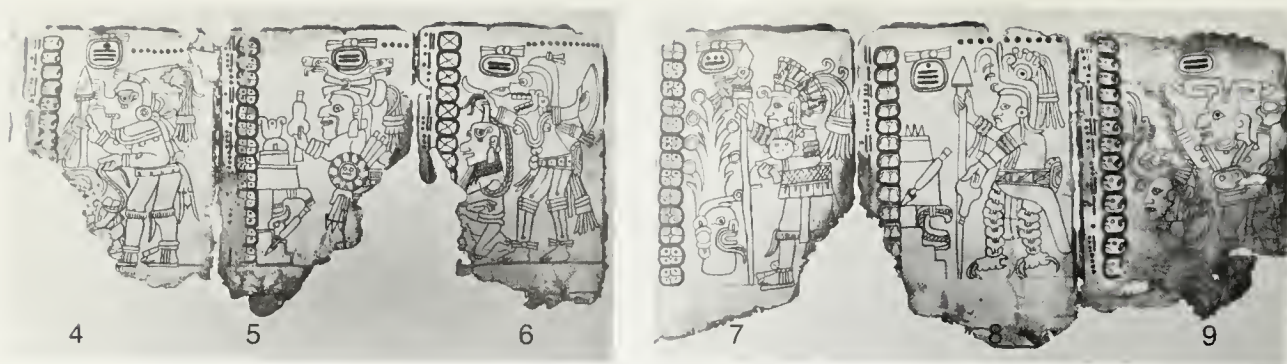


FIG. 64. A segment of the Grolier Codex, pp. 43*b*–45*b*. (Coe, 1973; courtesy of the author)

of the gods and their accouterments but also in the juxtaposition of dot and bar along with pure dot (Central Mexican) notation. As in the Dresden, we find a spear-wielding god, often with a bound captive. Adjacent to him a vertical array of 13 Tzol kin dates adorns the left edge of each page. Ring Numbers 10, 10, 8, 16, 10, 10, 8, 16, 10, 10, 8, 16 appear at the tips of the spears. To the right of these we find the numbers (in dot notation only) 4, 12, blank, 11, 4, 12, blank, 11, 4, 12, blank, 11. Coe interprets the latter to be coefficients of 20 to which the Ring Number must be added to arrive at successive Venus stations. Thus, if we begin the surviving portion of the table with the last visible sighting of Venus prior to disappearance behind the sun on page 1, we have

$4 \times 20 + 10 = 90$	pages 1, 5, 9	disappearance at superior conjunction
$12 \times 20 + 10 = 250$	pages 2, 6, 10	evening star
$0 \times 20 + 8 = 8$	pages 3, 7, 11	disappearance at inferior conjunction
$11 \times 20 + 16 = 236$	pages 4, 8, 12	morning star

Unlike Dresden 46–50, where a page represents a whole synodic period, in the Grolier one page connotes only one of the four stations within the synodic period. Its validity establishes the widespread use of these four peculiar divisions of the Venus cycle, hitherto expressed only in the Dresden. It seems unusual to see so many gods holding spears. The association of the spear with Venus in the Dresden is connected with the heliacal rising of the planet, clearly the central event in the ephemeris.

The position of the start of each station in the Tzol kin is correctly given by the signs in the left column. These are read in the usual manner. Thus, starting at the top of page 6 we have 12 Etz'nab. Adding 250 we arrive at 2 Lamat, which appears at the top of the column on page 7; adding 8 more we pick up 10 Cib (top, page 8), and so on. Given the extant portion of the table, Coe has reconstructed the original version, which he believes contained 20 pages. In all, thirteen trips through the table, each spanning 5×584 days, make the document valid for 37,960 days, the same as the Dresden version of the Venus ephemeris.

Not only do the same day signs appearing in the Venus table adorn the Grolier, but also the lub of the two tables (1 Ahau) is the same. Indeed, if the document is not authentic, then surely the faker must be

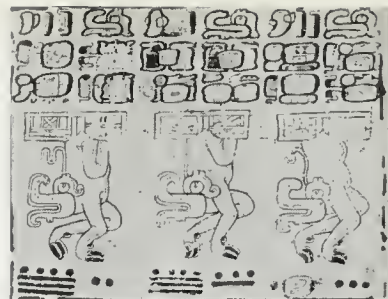
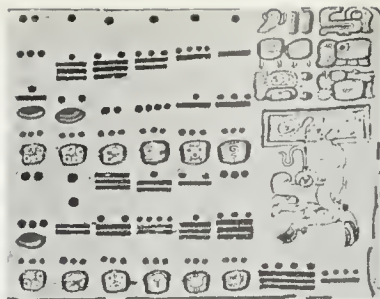
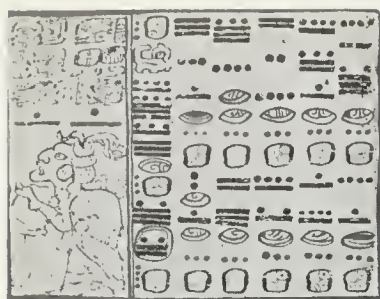
ASTRONOMY IN THE MAYA CODICES, III: A MARS TABLE?

Since Venus is prominently mentioned in the Maya inscriptions, should we not also expect to find the other planets? A few claims have been made, but the evidence is relatively scant. The best arguments emanating from a study of the monuments have been provided by Kelley (1975), who has discovered intervals on some Maya stelae (particularly on Stela 3 at Caracol, Belize) which might correspond to planetary synodic periods.³⁰ Among the manuscripts we find, across the middle of pages 43 to 45 of the Dresden, a multiplication table which may have derived from the 780-day synodic period of Mars. In fact, the ungulate animal with curled snout who adorns these pages (see also Fig. 61*a*, upper right corner) has come to be known as the "Mars beast." Due to an unfortunate coincidence, the Mars period (which actually averages 779.94 days) is nearly the same as a triple Tzol kin (3×260 days), so that in the absence of other evidence we cannot really be sure that aspects of the red planet are being depicted on these pages. On the other hand, recall that the Maya paid attention to Venus precisely because its period was commensurable with other cycles they observed. Nevertheless, the contents of pages 43*b* to 45*b* of the Dresden Codex are both interesting and controversial enough to warrant further examination. Accordingly, they are pictured in Fig. 65 and translated in Table 21.

The bulk of the table consists initially of multiples of 78 (Block VII) and Tzol kin dates (Block IX), as we can see in Figs. 65*a* and *b*. We begin at the bottom right of 44*b* and proceed to the left. Since the coefficient of the first entry (1×78) is 3 (Cimi) and 78 is evenly divisible by 13, we are assured that the coefficients of the remaining dates in the table also will be 3. Ten multiples of 78 are tabulated, though not in precise order, before the table begins to depart radically from the simple format. Soon other Maya numbers of importance (260, 364, and 780) begin to make their appearance. In 44*b*, column B (upper register), for example, we encounter 1.16.2.0 (= 13,000), which is $17 \times 780 - 260$, or $35 \times 364 + 260$, or 50×260 .³¹ On page 43*b*, beginning at the right side of Block VII, bottom right, we switch to integral multiples of 780, the triple Tzol kin, but this routine is also interrupted in favor of numbers which both lie within one Tzol kin of an integral multiple of 780 and are multiples of 364. Evidently, the tabulator possessed a deep desire to arrive at a 3 Lamat position in the sacred count, since this date is the only one to appear after the complex multiples enter.

It is worth noting that multiples of 78 occur elsewhere in the Dresden, most notably on page 59 following the eclipse table, where we find the series 1 to 9×78 followed by 3 to 19×780 , 2 to $9 \times 19 \times 780$, and, finally, 780 multiplied in turn by 172, 178, 180, and 185.

Block I of page 43*b*, which is separated from another table to its left by a double line, also contains a generous amount of confusing information. Following the all-important Tzol kin date 3 Lamat and the



a

page 43b

1	I			VII			
2				IX			
3				VII			
4				IX			
	A	B	C	D	E	F	G H

page 44b

1	VII					X		
2	IX					VI		
3	VII							
4	IX					II		
	A	B	C	D	E	F	G	H

page 45b

1	X					
2						
3						
4	VI					
5						
	II					
	A	B	C	D	E	F

b

FIG. 65. (a) The Dresden Codex, pp. 43b–45b (Thompson, 1972b; courtesy of American Philosophical Society, Philadelphia). (b) Schematic breakdown of the table:

- I. Initial Series data, including ring number and lub (note Mars beast)
- II. Dot and bar numerals suggesting counting intervals
- VI. The Mars beast pendent from sky bands
- VIII. Multiples of 78, 780, 364
- IX. Ritual calendar dates
- X. Augural and other glyphs (note Mars beast)

head of the Mars beast, we read the Long Count date 9.19.8.15.0, itself an integral multiple of 780 and 364, among other important Maya numbers; then comes 3 Lamat again, followed by the Ring Number 17.12 (= 352) and, finally, the familiar 4 Ahau (8 Cumhu) creation date.³² R. W. Willson (1924), the Harvard astronomer who pored over the astronomical inscriptions in the codices shortly after the turn of the century, translates this column freely as follows:

- 3 Lamat is the day of Mars.
- 1,435,980 is the Complete Period to the beginning of the ephemeris from
- 3 Lamat which is the Epoch and which is
- 352 days before
- 4 Ahau which is our Era. (P. 25)

According to Willson, the maker of the ephemeris was fixing the epoch, which in this case was the first 3 Lamat before the 4 Ahau creation date, at which Mars had the same aspect as when the table was intended to be used. Now, the number 352 figures prominently in the Mars theory because, as Willson shows, it is very nearly equal to the

Table 21. *Arrangement of Material on Pages 43b–44b of the Dresden Codex*

Page 43b					
A	B	C	D	E	F
1,435,980 =	109,200 =	131,040 =	72,800 =	(69,600)* =	30,940 =
3,945 × 364 =	300 × 364 =	360 × 364 =	200 × 364 =	80 × 780	85 × 364 =
1,841 × 780	140 × 780	168 × 780	93 × 780 + 260		40 × 780 – 260
3 Lamat**	3 Lamat	3 Lamat	3 Lamat	3 Lamat	3 Lamat
	151,320 =	3,900 =	3,380 =	2,340 =	1,560 =
352	582 × 260 =	5 × 780	4 × 780 + 260	3 × 780	2 × 780
	194 × 780				
4 Ahau	3 Lamat	3 Lamat	3 Lamat	3 Lamat	3 Lamat
Page 44b					
A	B	C	D	E	F
15,600 =	13,000 =	702 =	624 =	536 =	468 =
200 × 78 =	50 × 260 =	9 × 78	8 × 78	7 × 78	6 × 78
60 × 260	35 × 364 + 260 =				
	17 × 780 – 260				
3 Lamat	3 Lamat	3 Oc	3 Eb	3 Ix	3 Cib
780 =	390 =	312 =	234 =	156 =	78 =
10 × 78	5 × 78	4 × 78	3 × 78	2 × 78	1 × 78
3 Lamat	3 Etz'nab	3 Ahau	3 Ik	3 Kan	3 Cimi

* If we assume that the scribe added one dot too many in the fourth place, the number in the table is changed to 62,400, which is an exact multiple of 780.

** Should be 12 Lamat to correspond to the Long Count date.

average number of days between conjunctions and stationary points for Mars on its orbit.³³ Willson reasoned that the astronomer must have selected a 3 Lamat date on which he should begin a series of observations and then counted in reverse, employing progressively larger multiples of 780 until he arrived close to the 4 Ahau date of the present era (1,840 Mars periods). He then counted back one more period and arrived at the day 3 Lamat immediately preceding creation.

A set of user's instructions never fails to appear in a Maya astronomical table, and the Mars table is no exception. A band of isolated dot and bar numerals appears in Block II below the four pendant Mars beasts on pages 44b and 45b to serve this function. The numbers alternate between red and black, thus: 19 (black), 9 (red), 19 (black), 2 (red), 19 (black), 8 (red), 21 (black), 3 (red). Evidently, the red numbers represent day coefficients while the black indicate how much to add to each red number in order to proceed to the next. Since the lub of the table is 3 Lamat and the first entry in the table is 3 Cimi (page 44b, column F), 78 days later, Spinden (1924, pp. 64–68) has proposed a reasonable restoration for the counting scheme:

3 Lamat + 19 = 9 Manik + 19 = 2 Cimi
(lub of table) (1st black) (1st red) (2nd black) (2nd red)

+ 19 = 8 Chicchan + 21 = 3 Cimi
(3rd black) (3rd red) (4th black, Cimi used as zero) (resulting day name coefficient for first entry in table)

Finally, to complete the Mars table we have, as in the Venus and eclipse tables, a band of literary glyphs (Block X), including the Mars beast hanging from a sky band (Block VI) and an eclipse glyph (page 45*b*, column C, line 2, a kin sign on a half-black, half-white field).

Do pages 43*b*–45*b* of the Dresden Codex constitute a Mars table? The tabulations make less sense to us as an ephemeris than the Venus table, but there remains enough similarity between the structure of pages 43–45 and 46–50 for us to regard them with some astronomical seriousness. If the numbers do refer to the movement of Mars across the sky, why would the Maya break the motion down into units of 78 days? A brief glance at Table 6 tells us that Mars is in retrograde motion for approximately this length of time. But multiples of ten times the retrograde interval are difficult to fathom. Unlike Venus, Mars does not possess four universally recognizable stations in its celestial course, but only two—three at most if we care to consider the appearances as morning and evening star as separable events. Also in contrast with the Eclipse and Venus tables, we have no pictured intervals to separate the astronomical phenomena and no sets of upper and lower registers to tabulate intervals and cumulatives. It is conceivable that the ten stations may refer to different positions of the planet along the ecliptic. In this case the cloven-hoofed Mars beast might be suspended from bands representing component constellations of a Maya zodiac. To chart the course of a superior planet in this manner makes good sense, for such bodies, unlike Mercury and Venus, often appear opposite the sun in a darkened sky full of stars.

Is it only coincidental that the Ring Number 352, which we find nowhere else in the Codex, matches one of the fundamental periods in the Mars orbit? We must remember two things in this regard: (*a*) that 352 is the average of a series of periods between conjunction and stationary point which exhibit wide variations owing to the nonuniform nature of the motion of Mars in its orbit³⁴ and (*b*) that, though the stationary point in the retrograde motion of any planet would be a logically observable phenomenon for any naked-eye astronomer, the conjunction could not be witnessed at all. We might anticipate instead that the Maya astronomers would record heliacal rising or setting dates of the planet, for it was the first appearance of a celestial body that mattered most to them. We are forced to admit that if the Maya were recording the motion of Mars they were departing from their usual procedure. But let us also remember that too few manuscripts have been recovered for us to be able to decide what constitutes normal Maya astronomical procedure.

Lacking further evidence, the Mars table must remain enigmatic. We can do little more than speculate whether, a thousand years before the Western Renaissance, a Maya Kepler was also baffled and defeated by the erratic motion of the red planet. Perhaps this imperfect, incomplete table represents one of the most serious astronomical efforts of its time, an attempt to force another planet to conform to the same sort of celestial harmony as does steady Venus.

Other planetary intervals have been reported both in the manuscripts (e.g., Förstemann, 1904*c*) and on the carved stelae and lintels at many of the ruins (e.g., Kelley, 1975), but no true ephemeris which charts the mean motion, such as we find in the Venus table, has ever

survived the stage of simple suggestion. Counted from suitable base dates, as were the tropical year calculations at Palenque, nearly exact multiples of the synodic and even sidereal periods of Mercury, Jupiter, and Saturn have turned up. It is difficult to judge to what extent the Maya priests deliberately integrated these celestial intervals into the maze of historical data they carved on their monuments. The study of Maya dynastic history, which now proceeds with renewed fervor, is sure to shed light on many of the astronomical questions discussed in this chapter.

THE CASE FOR A ZODIAC

Given considerable evidence that the temporal cycles of the sun, moon, and at least some planets were being followed, we might anticipate that Mesoamerican astronomer-priests would also have been concerned about apparent planetary movement through space.

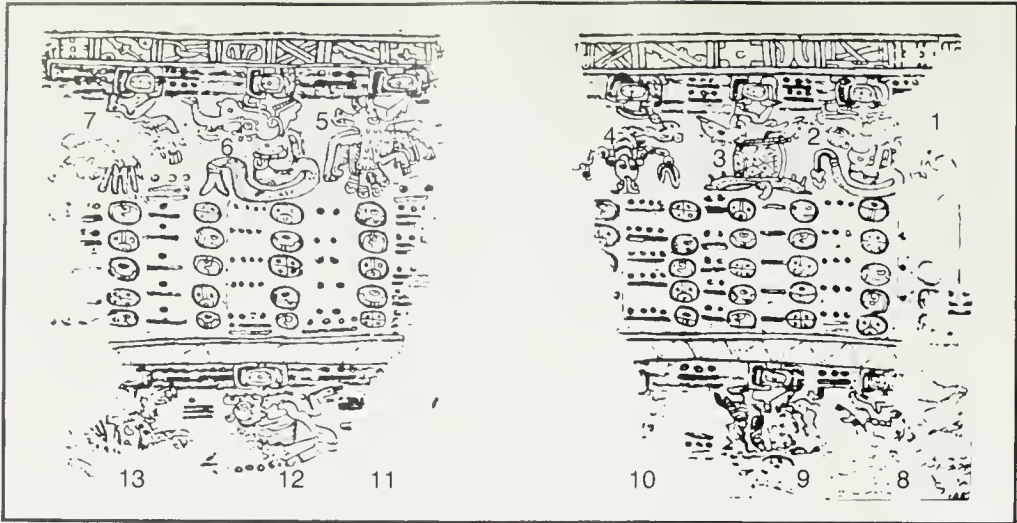
Since the heaviest celestial traffic occurs along the ecliptic, it seems logical that special attention might have been given to the stellar sign posts which mark that roadway. In ancient China, the equator (not the ecliptic) was divided into 27 (or 28) lunar mansions marked by named constellations to delineate the course of the moon among the stars. Our Western zodiac is defined as a narrow band (about 18° wide) flanking the ecliptic, which serves as its median line. It is segmented into 12 constellations, each occupying 30° lengths of the ecliptic, through which the moon, sun, and planets must pass.

Whether the concept of a zodiac existed in Mesoamerica, either via transfer from the Old World or arising independently, is a question which has not been answered to anybody's satisfaction. There is no doubt that the age-old debate between diffusionism and autochthonism colors the question. Perhaps the strongest evidence that the ancient Americans recognized a zodiac is provided by the remarkable similarity between the sequences of animals carved on a lintel on the eastern façade of the east wing of the Nunnery (Las Monjas) at Chichén Itzá, Yucatán, and painted on pages 23 and 24 of the Paris Codex. Let us analyze this parade of creatures and allow the reader to judge.

A fragment of this badly eroded codex, found abandoned amongst a pile of soot-covered papers in a chimney corner of the Bibliothèque Nationale in Paris in the 1850s, is reproduced in Fig. 66a. It pictures a number of animals hanging with clamped jaws from sun symbols below a continuous band, which, judging from the style of the rest of the codex, represents the body of the two-headed sky serpent. The parade of animals continues across the lower band, which is undecorated. All in all, thirteen animals are evident (four on the top of page 24, three on the top of page 23, and three on the bottom half of each page). They are laid out schematically in Table 22.

The most easily identifiable creatures in the codex are rattlesnake (2)—note the rattle; tortoise (3);³⁵ scorpion (4); a pair of birds (5) and (7)—the first is probably a vulture; and serpent (6). Less certain are frog (8); deer (9); death head (12); and peccary (13).

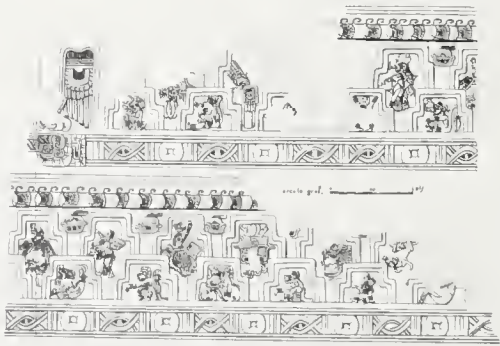
Could these animals represent constellations of the zodiac?³⁶ The scorpion constellation, discussed in Chapter III, is already familiar to



a



b



c

FIG. 66. A parade of animals in the Maya zodiac: (a) the Paris Codex, pp. 23–24 [courtesy of Akad. Druck-u. Verlag, Graz]; (b) lintel on the east wing of Las Monjas, Chichén Itzá (Maudslay, 1889–1902, 3:pl. 13); (c) segment of a stucco wall at Acancé, Yucatán (Marquina, 1964, fig. 244; courtesy of INAH, Mexico City). Note that the codex sequence—3 (tortoise), 4 (scorpion), 5 (vulture), 6 (serpent)—is repeated in reverse order in 17, 19, 21, and 23 of the Monjas relief (see Table 22 for identifications).

Table 22. *Schematic Arrangement of Animals Identified in the Paris Codex (Fig. 66a), Top, and in the Lintel of the East Doorway of Las Monjas (Nunnery) at Chichén Itzá (Fig. 66b), Bottom*

7 Bird	6 Serpent	5 Bird (vulture)	4 Scorpion	3 Tortoise	2 Rattlesnake	1 ?
13 Peccary	12 Death head	11 ?	10 ?	9 Deer	8 Frog	
1 ?	2 ?	3 Peccary	4 Bands	5 Lunar glyph	6 Imix glyph	
7 Bands	8 Death head	9 Bands	10 Bird	11 Bands	12 Bands	
13 Bands	14 Venus	15 Bands	16 Bands	17 Tortoise	18 Bands	
19 Scorpion	20 Bands	21 Vulture	22 Bands	23 Serpent	24 Bands	

us from Sahagún’s writings. Why do these animals hang from the band at the top? Does it represent the sky? Perhaps the celestial animals are devouring the planets which enter their respective houses. We often see eclipses and planetary conjunctions portrayed in this manner; for example, on the frieze of the Temple of the Plumed Serpents at Xochicalco serpents devour the disk of the sun in similar fashion.

That the sequence should be read from right to left is suggested by the ritual calendar which occupies the remainder of each page. We find columns of day names and numbers on page 24 followed by six more columns on page 23. Five horizontal rows span the two pages. Proceeding from right to left, we find that 28 days separate each entry. The reading proceeds exactly as in the uppermost portion of the Venus table. Examining the first visible upper row of page 24, we see 3 Kan. Adding 28, we arrive at 5 Eb, the entry in the next column to the left; an additional 28 enables us to arrive at 7 Ahau, and so on. Altogether, the 28-day period is registered thirteen times, totaling 364 days along each horizontal row; thus, five of these periods (1,820 days) are registered across the top of both pages. The number 28 elicits a lunar connection. It lies within two-thirds of a day of a lunar sidereal month. The ancient Maya may have been charting the course of the moon among the stars, dividing the lunar calendar into 13 months each of 28 days’ duration so that a lunar year would consist of 364 days, a number already familiar to us from the Mars table. Like our modern corrupted lunar year (12 months of approximately 30 days), such a calendar would soon slip out of phase with the lunar motion; a correction would be required. Perhaps the numerals 8 and double-8 occurring on the sky band between the pendent figures were used to this end. No one has worked out this intriguing problem to any general satisfaction.³⁷

The 1,820-day interval of five periods of 364 days can also be bro-

ken down into seven cycles of 260 days, the latter reinforcing the dedication of the Maya to the ritual calendar. A look at Table 5 reveals to our dismay that the 1,820-day interval has no direct connection with lunar eclipses.

On the east wing of the Nunnery at Chichén Itzá, 24 symbols appear in similar bandlike configuration (Fig. 66*b*, Table 22). Most of the entries are either crossbands, identical to those on the skybands in the codex, or Venus symbols; seven are animals. Four of the seven have been identified as the same creatures in the Paris Codex and they appear in the same sequence. These are the tortoise (17), scorpion (19), vulture (21), and serpent (23). Less certain common identifications (though out of sequence) are shared by the bird (10), death head (8), and peccary (3). This unusual correspondence is not simple coincidence. The codex and the lintel depict the same phenomena.

That the carved animals may also represent a zodiac is suggested by the integration of the Venus sign into each panel: he is the eyes of the death head and he also sits inverted beneath the other animal figures. Furthermore, the five days named in the Paris Codex—Lamat, Eb, Cib, Ahau, and Kan—coincide exactly with the five named days of the heliacal rising of Venus in the Dresden Codex. Finally, the attentive reader may note that Venus disappears for eight days in front of the sun before heliacal rising. Does this also tie in with the repeated numeral 8 across the top of the sky bands in the Paris? The Nunnery sequence may thus refer specifically to the passage of Venus through a segment of the Maya zodiac.

The proximity of the Nunnery building to the Caracol, which lies about 120 meters to the south, is worth noting. Though dated slightly later than the Nunnery, the Caracol clearly functioned as an astronomical observatory and appears to have served the special function of demarcating significant points in the celestial path of Venus.

Another possible zodiacal frieze (Fig. 66*c*) is present on the stucco wall of a palace at Acancéh, Yucatán. Here at least twenty sundry creatures, among them amphibians, snakes, birds, and forms possessing part-human and part-animal characteristics, are found incised in a plaster wall twelve meters in length. Decorative crossbands not unlike those in the Paris form a lower border to the frieze. Around the turn of the century when the idea of a transatlantic origin of an American zodiac seemed fashionable, a number of investigators attempted to equate many of these figures with animals represented in the Old World version of the zodiac. While these arguments taken by themselves were found wanting, the fundamental notion that the sequence represents a zodiacal progression of some sort may have some merit.

Though the aforementioned animal sequences, particularly those in the Paris Codex and over the entrance to the east wing of the Nunnery, provide strong evidence for the use of a zodiac in America, by no means do they constitute proof that such a concept existed. We will have to await further evidence to be sure.

Our studies of the astronomical tables in the codices suggest that the Maya priest-astronomers were using celestial events to glorify astrology. Their writings embody one vast divinatory scheme and seek a single goal: to establish an order to human existence by bringing the

naturally occurring astronomical cycles into accord with the 260-day calendar. This fundamental unit of time lies at the foundation of every almanac in the codices. In the 2,920-day Venus almanac we see the cyclic movement of a most inauspicious planet brought into harmony with the vague year as well as with the Tzol kin. In the lunar tables a count of 46 Tzol kins is necessary to create a re-entering moon-phase cycle which fits the possible occurrence of eclipses. The 1,820-day count in the Paris zodiacal table and the 780-day count of the Mars table were probably both chosen because they are exact multiples of the 260-day count. Even the important Long Count dates are contrived rather than accidental numbers.

Though we might be blinded by the ritual domination in the Maya calendar, if we look carefully we can gain a tantalizing glimpse of the supreme mental genius of these people. The monolithic tabulations on both monument and manuscript were born out of years of constant and careful monitoring of events transpiring on the celestial sphere. The almanacs, after all is said and done, must derive from the observational record.

Since we are fairly certain that Mesoamerican astronomers made horizon observations, we might ask how the elements of the calendar relate to those observations in particular. Given the tally of moons employed in the inscriptions, we must conclude that the lunar synodic period and the eclipse tables on pages 51–58 of the Dresden were derived only by counting and recording full moons over a long period.

A twentieth-century student of science might find it difficult to understand how the Maya could have developed a model for understanding eclipses without a knowledge of the relative orbits of the moon about the earth and the earth about the sun—and particularly the nodes of the moon's orbit. In a sense, the node concept is incorporated into Maya numerology rather than Maya geometry. For them, eclipse prediction had nothing to do with orbits or centrism of any kind; these are purely Western concepts.

For calendric purposes, the astronomers had little use for the position of the moon relative to the horizon. In this regard their system of astronomy is markedly different from that proposed for the Megalithic people of Great Britain. The observations of lunar extremes along the horizon have no place on the few tattered pages of the lone Maya lunar almanac which has survived. Data gleaned from a study of astronomical base lines and the orientation of buildings support this argument. There is no evidence in the astroarchaeological record which suggests that key lunar positions on the horizon were recorded in Mesoamerica.

For Venus, the story is quite different. The Venus tables mark heliacal risings and settings, both of which are horizon-based events. For the Maya, the appearance and disappearance of the planet is more important than its movement. As we shall learn in Chapter V, significant Venus alignments relative to the horizon are actually found in the Palace of the Governor at Uxmal and in the Caracol at Chichén Itzá, a building coinciding with the historical reference frame of the Dresden. As we shall also see, the 2,920-day cycle encapsulated by pages 46–50 of the Dresden is captured in the jambs of the Caracol windows. But how will those who claim to comprehend the Maya mentality ever ex-

plain the mysterious co-existence in the Dresden of a Venus disappearance interval (90 days) twice as long as the real one, all of this occurring within an almanac accurate to less than an hour per century?

The accomplishments of the Maya astronomers revealed in their inscriptions appear even more dazzling to our Western mentality when we realize that the celestial cycles were discovered without the aid of the instruments of precision that so greatly assisted the European astronomers in the development of our modern calendar during the Renaissance.

In Chapter V we shall learn that narrow tubes and windows were incorporated into the architectural plans of many Mesoamerican buildings especially for the purpose of making astronomical observations. As we have seen, notched sticks may also have been employed in the doorways of some of the buildings, but these devices differ totally in concept from the sextant, Jacob's staff, and armillary sphere—the graduated angle-measuring devices of the European astronomers.

Combining the information of Chapter V on the role of architecture and city planning with our discussion of naked-eye astronomy in Chapter III, we will show not only that the astronomical accomplishments of the Mesoamericans were entirely possible by direct observation of the heavens with the unaided eye but also that the calendar they developed is precisely what we would expect from a group of concerned and perceptive skywatchers who were in tune with the natural environment.

Tropical year calculations were every bit as accurate as the Venus almanac. Observations of the sun at the horizon and the heliacal rise-set dates of bright stars offer two methods of yielding the information we find in the inscriptions. As we shall also see, once again we find support in the astroarchaeological data that such solar observations were collected.

Appendix A. The Problem of the Correlation of Maya and Christian Dates

Among students of Maya calendrics, much attention (some would say too much) has been devoted to the attempt to match a given position in the Maya Long Count with a date in the Christian calendar. Since these endeavors involve various assumptions about the nature of Maya astronomy, we close this chapter with a brief review of the problem of calendar correlations. We make no attempt to solve the correlation problem, which at this stage is really insoluble in the eyes of most investigators.

Stated algebraically, the correlation question seeks a solution to the equation

$$LC + A = JD,$$

where LC is a Long Count date in the Maya calendar and JD a Julian date in the Christian calendar. Modern astronomers define the Julian date as the number of days elapsed since January 1, 4712 B.C. The term "A" linking the two is called the "Ahu equation," since the starting

Table 23. *Some Suggested Maya-Christian Calendar Correlations*

<i>Correlation</i>	<i>A</i>
Smiley	482,699
Makemson	489,138
Spinden	489,384
Goodman-Martínez-Thompson	584,283
Kreichgauer	626,927
Hochleitner	674,265
Escalona Ramos	679,108
Weitzel	774,078

date 0.0.0.0.0 is an Ahau date. In Table 23 we list a few of the proposed values of *A* which have been taken seriously during the past few decades. They span a range, from earliest to latest, of nearly eight centuries.

Only the Spinden and the Goodman-Martínez-Thompson (GMT) correlations have ever attracted a wide following. In the last three decades the latter has emerged as the most successful of all those which have been proposed; nevertheless, the reader should be reminded that even its own proponents admit that the GMT is far from perfect.

The notion that only one Ahau equation is correct for the entire Maya world rests upon two assumptions:

- (a) That a single unified calendar was kept throughout the Maya area during the time the codices and inscriptions were written
- (b) That no attempt was made to alter the calendar since the time of these writings

Regarding the first assumption, we know that the method of counting moons was changed at Copán at the height of the Classic period. Might the Long Count procedure also have undergone adjustment? Both assumptions have only the advantage that they are simple.³⁸

The ideal correlation must be consistent with evidence provided from historical documents appearing at the time of the conquest, inscriptional evidence, astronomical evidence, ceramics, and stylistic considerations. A correlation derived solely from the inscriptions seems most ideal, since one need not worry about the validity or reliability of postconquest historical documents.

In this section, we discuss briefly the arguments underlying the foundation of the GMT correlation, which has a historical basis. For comparison, we also discuss the foundations of one of the representative astronomically based correlations, that of Smiley. Finally, we conclude our discussion of calendar by developing a simple scheme for converting Maya dates to Christian dates.

The principal foundation underlying the Ahau equation of the GMT correlation rests upon a historical document, the Chronicle of Oxcutzcab (Yucatán), which according to Teeple (1930, p. 101) states that a tun ended on 13 Ahau 8 Xul in the year A.D. 1539.³⁹ Now, there

are only two or three Long Count dates in Maya history which fulfill the required condition. A 13 Ahau 8 Xul date repeats every 52 vague years (18,980 days). A specific Calendar Round date will coincide with a tun ending every 341,640, or 2.7.9.0.0, days (the lowest integral multiple of both 18,980 and 360). To decide which Long Count is correct, we employ the talents we developed earlier in this chapter. We start by listing the first 13 Ahau 8 Xul date and all which follow 0.0.0.0.0:

Given 0.0.0.0.0 4 Ahau 8 Cumhu,
to get to the first 8 Xul date, add + $\frac{6.5}{0.0.0.6.5}$ 12 Chicchan 8 Xul.

It is 235 days from 12 Chicchan to 13 Ahau, the desired katun ending date, and 365 days from 8 Xul to the next 8 Xul. To fit the appropriate Calendar Round components together, we must (a) go through the vague year an integral number of times and (b) go through the Tzol kin wheel an integral number of times with a remainder of 235. This condition is met by

$27 \times 365 \text{ days} = 37 \times 260 \text{ days} + 235 = 9,855 \text{ days}.$

Thus, our first 13 Ahau 8 Xul date can be obtained by adding 9,855 days (1.7.6.15) to 0.0.0.6.5:

0. 0. 0. 6. 5
+ 1. 7. 6.15

0. 1. 7.13. 0 13 Ahau 8 Xul
+ 2. 7. 9. 0. 0

2. 8.16.13. 0 13 Ahau 8 Xul

Now, one Calendar Round before this date, we have a 13 Ahau 8 Xul date which also ended a tun. Subtracting, we arrive at six possible choices for a solution:

2. 8.16.13. 0 13 Ahau 8 Xul
- 2.12.13. 0

2. 6. 4. 0. 0 13 Ahau 8 Xul and tun ending (first choice)
+ 2. 7. 9. 0. 0

5.13.13. 0. 0 13 Ahau 8 Xul and tun ending (second choice)
+ 2. 7. 9. 0. 0

7. 1. 2. 0. 0 13 Ahau 8 Xul and tun ending (third choice)
+ 2. 7. 9. 0. 0

9. 8.11. 0. 0 13 Ahau 8 Xul and tun ending (fourth choice)
+ 2. 7. 9. 0. 0

11.16. 0. 0. 0 13 Ahau 8 Xul and tun ending (fifth choice)
+ 2. 7. 9. 0. 0

14. 3. 9. 0. 0 13 Ahau 8 Xul and tun ending (sixth choice)

Of the six choices for a matching Long Count, only the last three are worth considering. Even at that, the last date places all the inscriptions before the Christian era, thereby conflicting with the radiocarbon data, and the cycle 9 date would have most of them coincide with the conquest. The cycle 11 date (fifth choice) seems to be the only sensible one. This date ended not only a tun but also a katun. Other historical documents corroborate this interpretation by placing a katun ending within a few years of A.D. 1540.

Two other historical fragments enable us to zero in on a specific Christian date to match 11.16.0.0.0:

(a) In his writings, Bishop Diego de Landa places a Maya calendar side by side with a Christian calendar. Therein he sets 12 Kan 2 Pop opposite July 16, 1553.

(b) In the book of Chilam Balam, 11 Chuen 18, or 19 Zac, is set opposite February 15, 1544.

All the assembled data are consistent with the equation November 3, 1539 = 11.16.0.0.0, give or take a few days. Thus, for the GMT, or "11.16," correlation we find that $A = 584,283$, and the corresponding zero point of the calendar turns out to be August 12, 3113 B.C., a date of no obvious historical or astronomical significance.⁴⁰

A strong point in favor of the 11.16 correlation, in addition to historical consistency, is the agreement in many cases between the occurrence of astronomical events recorded in the inscriptions and those derived on the basis of modern astronomical calculations. For example, take the age of the moon depicted in Stela 3 at Tikal (Fig. 60b). The inscribed Long Count date, 9.2.13.0.0, is equivalent to A.D. 488 June 15, according to the GMT correlation. The age of the moon given by the Lunar Series date inscribed on the stela was seventeen days, which lies within two days of that calculated from modern astronomical theory for the corresponding Christian date.

We also find good agreement between the GMT correlation and the Dresden Codex. The Long Count date 9.9.9.16.0 on page 24, which opens the Venus tables, can be converted using the GMT correlation to A.D. February 5, 623. This turns out to be a new moon date and lies within twenty days of a Venus conjunction date. Finally, the three usable Initial Series dates at the top of page 52 of the Dresden Codex (the eclipse tables) fall on new moon, full moon, and new moon dates, respectively. The middle date marked a lunar eclipse, that of November 23, 755. When such coincidences take place repeatedly, we develop a tendency to become convinced.

In contrast to the historically derived GMT correlation, the Smiley correlation represents a different philosophy in pursuing an answer to the correlation question. Eschewing all historical dates as unreliable, Smiley focuses on a purely astronomical solution to the problem, laying as a foundation for his correlation the assumption that certain inscriptions record astronomical events and intervals between events. The Ahau equation given by the Smiley correlation is $A = 482,699$, which puts the zero point 278 years earlier than does the GMT. Smiley's number is based upon an assumption which is not unreasonable in view of our examination of the Maya calendar keeping: that in the Dresden Codex, Maya astronomers were attempting to link solar eclipses to planetary conjunctions, especially those of Venus. Given the Long Count date on page 24 and derived dates relating to pages 46–50:

- (a) 9. 8. 3.16. 0 1 Ahau 3 Xul
- (b) 9. 9. 9.16. 0 1 Ahau 18 Kayab (p. 24)
- (c) 9.11. 3. 2. 0 1 Ahau 13 Mac
- (d) 9.12.16. 6. 0 1 Ahau 8 Chuen
- (e) 9.14. 2. 6. 0 1 Ahau 18 Uo
- (f) 9.15.15.10. 0 1 Ahau 18 Pax

Smiley looked for a solar eclipse visible in Central America near the date of a Venus conjunction. He found that A.D. December 22, 344, fit this condition, and he equated it with the key Long Count date on page 24 (date (b) above) to get his Ahau equation. Using the Smiley number, each of the remaining dates listed above was found to lie not only within one day of a possible eclipse but also "remarkably close" (Smiley's words) to inferior and superior conjunction dates of Venus; the differences for the dates listed above are -13 , $+4$, -6 , -14 , -1 , and -10 days. Smiley also finds moon ages to be in substantial agreement with those given by Glyphs D and E on many stelae. His correlation also attributes astronomical significance to the three Initial Series dates on page 52 of the eclipse table. They fall on an autumnal equinox, a full moon, and a solar eclipse, that of A.D. October 23, 477. However, one must keep in mind that five of the six dates listed above that Smiley uses in deriving his correlations are not written as Initial Series dates but are derived from positions in the Calendar Round. Three other 1 Ahau dates are derivable from the Venus table, but he chooses to ignore these.

Other purely astronomical correlations which have been offered are based upon the supposition that the Maya priests were recording the appearance of comets, novae, planetary conjunctions involving the other planets, and so on. In many cases the validity of a purely astronomical correlation is difficult to judge on its own ground. Quite like the question of building orientation, there is an inherent temptation to play with the numbers. Given enough tolerance, a fit with any astronomical data is possible. Smiley's critics have suggested that the pathway he has undertaken to the understanding of Maya astronomy and calendar may be cluttered with the boulders of coincidence.

Kelley (1976) has suggested that no historically or astronomically based correlation—even the old Thompson correlation (constant 584,285) or the modified version (constant 584,283)—can be regarded as absolutely correct, because of discrepancies with known astronomical data in the codices and on the monuments. Kelley has also doubted some of the historical bases for the Thompson correlation and gives a thorough exposition of the correlation problem in his text. Though, in my opinion, he often takes considerable latitude in establishing the basic astronomical criteria by which to evaluate correlations (p. 32), Kelley is correct to stress the idea that one must constantly test the various correlations for consistency against known astronomical and historical facts as they become available.

One example of such a test might consist of calculating moon ages according to different correlations for dates recorded on a selection of stelae, then noting how well the D and E glyphs, assumed to correspond to the Long Count dates on the stelae, accord with the predictions. In Table 24, we show the results of a statistical test pitting the Spinden against the modified (GMT or Thompson) correlation. Long Count dates on Copán stelae according to Morley (1920) form the subject matter. The dates are tabulated in the second column; the recorded value of the age of the moon appears in the third. In the last two columns we have used the method of Appendix B of this chapter to convert to Christian dates, then we simply look up the moon age in Gold-

Table 24. *Copán Stelae: Recorded Moon Ages Contrasted with Moon Ages Predicted by Spinden and GMT Correlations (Deviations in parentheses)*

Monument	Long Count Date	Moon Age Indicated by Glyphs D & E	Moon Age Predicted by Spinden GMT	
Stela 20	9.1.10.0.0	25	8 (13)	25 (0)
H.S.* Date #1	9.5.19.13.0	25	26 (1)	13 (11)
Stela 9	9.6.10.0.0	25	8 (12)	27 (2)
H.S. Date #3	9.7.5.0.8	2	13 (11)	3 (1)
Stela 7	9.9.0.0.0	13	27 (14)	13 (0)
Stela P	9.9.10.0.0	9	24 (-14)	10 (1)
H.S. Date #5	9.9.14.17.5	23	7 (14)	23 (0)
Stela 12	9.10.15.0.0	3	15 (12)	5 (2)
Stela 23	9.10.18.12.8	5	15 (10)	4 (-1)
Stela 10	9.10.19.13.0	23	5 (12)	23 (0)
Stela 19	9.10.19.15.0	4	15 (11)	3 (-1)
Stela 13	9.11.0.0.0	5	15 (10)	4 (-1)
Altar Stela 5	9.11.15.0.0	28	11 (12)	27 (-1)
Stela 1	9.11.15.14.0	12	25 (13)	11 (-1)
Stela I	9.12.3.14.0	0	25 (-5)	11 (11)
Altar H'	9.12.8.3.9	22	5 (12)	21 (-1)
Stela 6	9.12.10.0.0	22	8 (15)	24 (2)
Altar K	9.12.16.7.8	0	19 (-11)	8 (8)
Stela J	9.13.10.0.0	18	27 (9)	15 (-3)
Stela 5	9.13.15.1.0	8	1 (-7)	17 (9)
Stela A	9.14.19.8.0	15	0 (-15)	16 (1)
Stela D	9.15.5.0.0	9	21 (12)	9 (0)
H.S. Date #11	9.15.12.10.10	24	15 (-9)	2 (8)
Stela M	9.16.5.0.0	5	17 (12)	4 (-1)
Stela N	9.16.10.0.0	1	14 (13)	2 (1)
Standard deviation in days from glyphic value			11.6	4.0

* Hieroglyphic Stairway.

stine’s (1973) tables. Finally, in parentheses after each moon age, we tabulate the difference between calculated and inscribed lunar ages assumed to be measured from new moon. At the bottom of each of the last two columns we calculate the standard deviation in days from the glyphic value.

While neither correlation agrees absolutely with the moon age recorded on each stela, the GMT emerges from the test as the better of the two correlations (at least for the Copán calendar) with nearly two-thirds of the predictions (actually “postdictions”) of moon age falling within a day of reality. While this simple test, considered by itself, fails to prove that the GMT is the only reasonable correlation, when we take it in hand with other statistical tests we are led inexorably to think of the GMT as the most representative correlation at the present time. But the issue is by no means closed.

One fact about the correlation question seems clear: the correlation meeting the widest possible variety of tests from all quarters shall be the closest to the truth. Some relevant information, as summarized by Kelley (1976 and private communication), includes:

- (a) Modern and colonial data on the 52-year cycle (generally consistent, with a possible range of variation of a few days).
- (b) Colonial data on the katun cycle—some of this information is inconsistent and probably unusable with reference to Classic period inscriptions.
- (c) Evidence of calendar corrections in Mixtec and Zapotec materials, suggesting the possibility that (a) is not relevant for the Classic period.
- (d) The historical and archaeologic data, which make it highly likely that the Toltec period had ended by about A.D. 1260 and that the Toltec period began at about 10.2.0.0.0 of the Maya Long Count—hence, the length of this period is the crucial factor: less than 50 years seems quite unlikely and over 600 years seems even less likely, but within that span almost anything is possible.
- (e) Radiocarbon dating, archaeomagnetism, and other geophysical techniques suggest that the end of the Classic period occurred about A.D. 850, with a tolerance of about 300 years.
- (f) Astronomical data: probably the only way that the problem can be solved is by getting more control of our astronomical data, but satisfactory control can only be achieved with a correct correlation.

Among the crucial problems:

1. The Venus table—what is the purpose of the 9.9.9.16.0 date? Did the Maya correct the table or did they use it uncorrected as a measure of the degree of shift of observations from tabular values? If the latter, then the base date 12.19.13.16.0 1 Ahau 18 Kayab was probably back-calculated to correspond to a true heliacal rising of Venus, but how accurate were the calculations?
2. Eclipse table—same kind of questions: Is it a table of visible eclipses or a warning table? Had a "standard" lunar base shifted from reality as Spinden (1924) believed?
3. Tropical year—can stations other than equinoxes and solstices be made plausible at one-fourth year intervals?
4. Jupiter, Saturn, Mars—knowledge of their calendar names and properties may be crucial in solving the correlation problem, but even that which is already known suggests that most existing correlations do not adequately meet all these new constraints.

Appendix B. A Scheme for the Conversion of Maya Dates

We conclude with a simple procedure for converting a Maya Long Count date into a Christian date and vice versa. For our first example we choose the Long Count date of the Leyden Plate, 8.14.3.1.12, and we use the GMT correlation ($A = 584,284$):

1. Using Table 14, we convert the Long Count into days:

Table 25. *Julian Day Number of Zero Day for Each Century (500 B.C. to A.D. 1500)*

Century Year		JD No.
B.C.	500	1,538,432
	400	1,574,957
	300	1,611,482
	200	1,648,007
	100	1,684,532
	0	1,721,057
A.D.	100	1,757,582
	200	1,794,107
	300	1,830,632
	400	1,867,157
	500	1,903,682
	600	1,940,207
	700	1,976,732
	800	2,013,257
	900	2,049,782
	1000	2,086,307
	1100	2,122,832
	1200	2,159,357
	1300	2,195,882
	1400	2,232,407
	1500	2,268,932
	1600	2,305,457
	1700	2,341,982
	1800	2,378,507
	1900	2,415,032

8 Baktuns = 1,152,000 days

14 Katuns = 100,800

3 Tuns = 1,080

1 Uinal = 20

12 Kins = 12

Total = 1,253,912 days

2. To this total we add the Ahau equation for the GMT (Table 23), thus arriving at the Julian Day number:

1,253,912 days

+ 584,283

1,838,195 days

3. Table 25 converts the zero day of each century into a Julian Day number. From this table, we select the Julian Day number which is closest to *but smaller than* the given number of days. In this case, it

Table 26. *Fraction of a Year Represented by a Given Date*

Day of Month	Jan.	Feb.	Mar.	Apr.	May
0.0		0.0821	0.1588	0.2437	0.3258
1.0	.0000	.0849	.1615	.2464	.3285
2.0	.0027	.0876	.1643	.2491	.3313
3.0	.0055	.0904	.1670	.2519	.3349
4.0	.0082	.0931	.1698	.2546	.3368
5.0	0.0110	0.0958	0.1725	0.2574	0.3395
6.0	.0137	.0986	.1752	.2601	.3422
7.0	.0164	.1013	.1780	.2628	.3450
8.0	.0192	.1040	.1807	.2656	.3477
9.0	.0219	.1068	.1834	.2683	.3505
10.0	0.0246	0.1095	0.1862	0.2711	0.3532
11.0	.0274	.1123	.1889	.2738	.3559
12.0	.0301	.1150	.1917	.2765	.3587
13.0	.0329	.1177	.1944	.2793	.3614
14.0	.0356	.1205	.1971	.2820	.3641
15.0	0.0383	0.1232	0.1999	0.2847	0.3669
16.0	.0411	.1259	.2026	.2875	.3696
17.0	.0438	.1287	.2053	.2902	.3723
18.0	.0465	.1314	.2081	.2930	.3751
19.0	.0493	.1342	.2108	.2957	.3778
20.0	0.0520	0.1369	0.2136	0.2984	0.3806
21.0	.0548	.1396	.2163	.3012	.3833
22.0	.0575	.1424	.2190	.3039	.3860
23.0	.0602	.1451	.2218	.3066	.3888
24.0	.0630	.1478	.2245	.3094	.3915
25.0	0.0657	0.1506	0.2272	0.3121	0.3943
26.0	.0684	.1533	.2300	.3149	.3970
27.0	.0712	.1561	.2327	.3176	.3997
28.0	.0739	.1588	.2355	.3203	.4025
29.0	.0767		.2382	.3231	.4052
30.0	0.0797		0.2409	0.3258	0.4079
31.0	.0821		.2437		.4107

After Neugebauer, 1912, pp. 343-345.

will be 1,830,632 (opposite A.D. 300). Subtract this number from the given number of days:

$$\begin{array}{r} 1,838,195 \text{ days} \\ - 1,830,632 \\ \hline 7,563 \text{ days} \end{array}$$

Thus, the reduced date is equivalent to A.D. 300 + 7,563 days.

4. Next, we convert 7,563 days into an equivalent number of years, months, and days of the month. Dividing by the number of days in a tropical year:

<i>Jun.</i>	<i>Jul.</i>	<i>Aug.</i>	<i>Sep.</i>	<i>Oct.</i>	<i>Nov.</i>	<i>Dec.</i>
0.4107	0.4928	0.5777	0.6626	0.7447	0.8296	0.9117
.4134	.4956	.5804	.6653	.7474	.8323	.9145
.4162	.4983	.5832	.6680	.7502	.8351	.9172
.4180	.5010	.5859	.6708	.7529	.8379	.9199
.4216	.5038	.5887	.6735	.7557	.8405	.9227
0.4244	0.5065	0.5914	0.6763	0.7584	0.8433	0.9254
.4271	.5093	.5941	.6790	.7611	.8460	.9282
.4299	.5120	.5969	.6817	.7639	.8488	.9309
.4326	.5147	.5996	.6845	.7666	.8515	.9336
.4353	.5175	.6023	.6872	.7694	.8542	.9364
0.4381	0.5202	0.6051	0.6900	0.7721	0.8570	0.9391
.4408	.5229	.6078	.6927	.7748	.8597	.9418
.4435	.5257	.6106	.6954	.7776	.8624	.9446
.4463	.5284	.6133	.6982	.7803	.8642	.9473
.4490	.5312	.6160	.7009	.7830	.8679	.9501
0.4518	0.5339	0.6188	0.7036	0.7858	0.8707	0.9528
.4545	.5366	.6215	.7064	.7885	.8734	.9555
.4572	.5394	.6242	.7091	.7913	.8761	.9583
.4600	.5421	.6270	.7119	.7940	.8789	.9610
.4627	.5448	.6297	.7146	.7967	.8816	.9637
0.4654	0.5476	0.6325	0.7173	0.7995	0.8843	0.9665
.4682	.5503	.6352	.7201	.8022	.8871	.9692
.4709	.5531	.6379	.7228	.8049	.8898	.9720
.4737	.5558	.6407	.7255	.8077	.8926	.9747
.4764	.5585	.6434	.7283	.8104	.8953	.9774
0.4791	0.5613	0.6461	0.7310	0.8132	0.8980	0.9802
.4819	.5640	.6489	.7338	.8159	.9008	.9829
.4846	.5667	.6516	.7365	.8186	.9035	.9856
.4873	.5695	.6544	.7392	.8214	.9062	.9884
.4901	.5722	.6571	.7420	.8241	.9090	.9911
0.4928	0.5750	0.6598	0.7447	0.8268	0.9117	0.9939
	.5777	.6626		.8296		.9966

$$7,563 \div 365.2422 = 20.7068 \text{ years.}$$

The date becomes A.D. 320.7068.

5. To convert the decimal portion of the date into month and day of month, we employ Table 26. Thus, the date nearest .7068 is found to be September 16. Since A.D. 320 was a leap year, one day must be deducted. The completed conversion reads

$$8.14.3.1.12 = \text{A.D. September 15, 320 (GMT).}$$

As a second example, we convert the date on Stela 3 at Tikal (9.2.13.0.0) using the Spinden correlation ($A = 489,384$).

1. Convert to decimal:

$$\begin{array}{rcl}
 9 \text{ Baktuns} & = & 1,296,000 \text{ days} \\
 2 \text{ Katuns} & = & 14,400 \\
 13 \text{ Tuns} & = & 4,680 \\
 0 \text{ Uinals} & = & 0 \\
 0 \text{ Kins} & = & 0 \\
 \hline
 & & 1,315,080 \text{ days}
 \end{array}$$

2. Add the Ahau equation for the Spinden correlation:

$$\begin{array}{rcl}
 1,315,080 \text{ days} \\
 + 489,384 \\
 \hline
 1,804,464 \text{ days}
 \end{array}$$

3. Select the appropriate century Julian Day number from Table 25 and subtract:

$$\begin{array}{rcl}
 1,804,464 \text{ days} \\
 - 1,794,107 \text{ (A.D. 200)} \\
 \hline
 10,357 \text{ days}
 \end{array}$$

The date is A.D. 200 + 10,357 days.

4. Convert 10,357 days to years:

$$10,357 \div 365.2422 = 28.3565 \text{ years.}$$

The date is A.D. 228.3565.

5. Use Table 26 to convert to month and day of month, again remembering to deduct one day since A.D. 228 was a leap year. The answer:

$$9.2.13.0.0 = \text{A.D. May 10, 228 (Spinden).}$$

Since it may be useful to know how to convert a Christian date into Maya notation, we also illustrate this procedure with an example. Suppose we wish to convert A.D. December 22, 344, the date on which an eclipse of the sun occurred at the winter solstice, into Maya form using the Smiley correlation.

1. Working the technique of the first two examples backward, we start by using Table 26 to convert December 22 to a decimal fraction of a year.⁴¹ Since A.D. 344 was a leap year, we must move forward one row in the table. Thus,

$$\text{A.D. December 22, 344} = \text{A.D. } 344.9747.$$

2. We divide this interval into the sum of centuries plus the nearest whole number of days:

$$\begin{array}{rcl}
 344.9747 \text{ years} & = & 300 \text{ years} + 44.9747 \text{ years} \\
 & & 300 \text{ years} + 44.9747 \times 365.2422 \text{ days/year} \\
 & & 300 \text{ years} + 16,427 \text{ days}
 \end{array}$$

3. Next, we use Table 25 to convert the century year into Julian days; thus,

$$300 \text{ years} = 1,830,632 \text{ days}$$

$$\begin{aligned}\text{A.D. December 22, 344} &= 1,830,632 \text{ days} + 16,427 \text{ days} \\ &= 1,847,059 \text{ days.}\end{aligned}$$

4. The Ahau equation must next be solved for Long Count using $A = 482,699$, the Smiley correlation number (Table 23). Thus,

$$\text{LC} = \text{JD} - A$$

$$\text{LC} = 1,847,059 - 482,699$$

$$\text{or } \text{LC} = 1,364,360$$

5. Finally, we can use Table 14 to convert this number of days to a Maya Long Count, with the result that $1,364,360 \text{ days} = 9.9.9.16.0$. Thus,

$$\text{A.D. December 22, 344} = 9.9.9.16.0,$$

a result corresponding precisely to that discussed in the text.

ADDITIONAL READINGS

The treatment of timekeeping and calendar in this chapter has been geared specifically toward astronomy. In order to obtain a broader perspective on the subject, the reader should consult other references. Among the most useful general treatments of Maya calendrics are:

- Morley, S. G. 1975. *An introduction to the study of Maya hieroglyphic writing*. New York: Dover. [Contains numerous examples of decipherment]
- Satterthwaite, L., Jr. 1947. *Concepts and structures of Maya calendrical arithmetics*. Joint Publications of the University of Pennsylvania Museum and the Philadelphia Anthropological Society, 3. Philadelphia. [Focuses principally on the question of how the computations were done, the astronomy playing a secondary role]
- Spinden, H. J. 1924. *The reduction of Mayan dates*. Peabody Museum of American Archaeology and Ethnology Papers, 6(4). [Includes the basis for the Spinden correlation]
- Teeple, J. E. 1930. *Maya astronomy*. Carnegie Institution of Washington Publications, 405, contr. 2. [Especially useful for a discussion of the Supplementary Series]

General discussions of Maya hieroglyphic writing, especially in the realm of the current state of the art, can be found in:

- Kelley, D. H. 1976. *Deciphering the Maya script*. Austin: University of Texas Press. [Also gives a complete survey of the correlation question]
- . 1977. Maya astronomical tables and inscriptions. In *Native American astronomy*, ed. A. F. Aveni, pp. 57–73. Austin: University of Texas Press.
- , and K. A. Kerr. 1974. Maya astronomy and astronomical glyphs. In *Mesoamerican writing systems*, ed. E. Benson, pp. 179–215. Washington, D.C.: Dumbarton Oaks, Research Library and Collections.
- Lounsbury, F. G. 1978. Maya numeration, computation and calendrical astronomy. *Dictionary of scientific biography* 15: suppl. 1, ed. C. C. Gillispie, pp. 759–818. New York: Scribner's.

- Spinden, H. J. 1930. The Maya dates and what they reveal. Brooklyn Institute of Arts and Sciences, *Science Bulletin* 4(1).
Thompson, J. E. S. 1971. *Maya hieroglyphic writing: An introduction*. 3d ed. Norman: University of Oklahoma Press.
———. 1972. *Maya hieroglyphs without tears*. London: British Museum. [A less ambitious treatment]

Catalogs of hieroglyphs include:

- Thompson, J. E. S. 1962. *A catalog of Maya hieroglyphs*. Norman: University of Oklahoma Press.
Zimmerman, G. 1956. *Die Hieroglyphen der Maya Handschriften*. Universität Hamburg, Abhandlungen aus dem Gebiet der Auslandskunde, 57. Hamburg.

Excellent discussions of the Maya codices include:

- Thompson, J. E. S. 1972. *A commentary on the Dresden Codex, a Maya hieroglyphic book*. American Philosophical Society Memoirs, 93. Philadelphia.
Villacorta, J., and C. Villacorta. 1977. *Codices mayas*. Guatemala City: Reproducidos y Desarrollados.

The Grolier Codex appears in:

- Coe, M. D. 1973. *The Maya scribe and his world*. New York: Grolier.

For two thorough discussions on the origin of hieroglyphic writing, see:

- Coe, M. D. 1976. Early steps in the evolution of Maya writing. In *Origins of religions, art, and iconography in pre-classic Mesoamerica*. UCLA Latin American Studies Series, 31. Los Angeles.
Marcus, J. 1976. Origins of Mesoamerican writing. *Annual Review of Anthropology* 5: 35–68.

For a collection of papers on astronomy and calendar, see:

- Aveni, A. F., ed. 1975. *Archaeoastronomy in pre-Columbian America*. Austin: University of Texas Press.
———, ed. 1977. *Native American astronomy*. Austin: University of Texas Press. [Both texts also provide extensive bibliographies]

One of the best early treatments of Maya astronomy and calendar appears in:

- Willson, R. W. 1924. *Astronomical notes on the Maya codices*. Peabody Museum of American Archaeology and Ethnology Papers, 6(3).

The problem of calendar correlations is treated in:

- Thompson, J. E. S. 1930. *Maya chronology: The correlation question*. Carnegie Institution of Washington Publications, contr. 2.

The philosophy of Maya and Mexican timekeeping is treated by:

- Brotherston, G. 1975. Time and script in ancient Mesoamerica. *Indiana* 3:9–29.
- . 1976. Mesoamerican description of space, II. *Ibero-Americanische Archiv* (Berlin) 2:39–62.
- . 1979. *Image of the New World*. London: Thames and Hudson. [A general treatment]
- , and D. Ades. 1975. Mesoamerican description of space, I: Myths, stars and maps, and architecture. *Ibero-Americanische Archiv* (Berlin) 1:279–305.
- León-Portilla, M. 1973. *Time and reality in the thought of the Maya*. Boston: Beacon Press.

V. Astroarchaeology and the Place of Astronomy in Ancient American Architecture

*"Then to her Patron Saint a previous rite
Resounded with deep swell and solemn close,
Through unremitting vigils of the night,
Till from his couch the wished-for Sun uprose.*

*He rose, and straight—as by divine command—
They, who had waited for that sign to trace
Their work's foundation, gave with careful hand
To the high altar its determined place."*

—Wordsworth, "On Seeing the Foundation Preparing for the Erection of Rydal Chapel, Westmoreland" (Dinsmoor, 1939, p. 102)

THE ORIENTATION MOTIVE

Since none of the buildings of modern New York, Vienna, or Tokyo exhibit purposeful astronomical orientations beyond simple cardinality, why should we expect the ancients to have behaved differently when they constructed their buildings? Our quotation from a poem by Wordsworth¹ provides a clue to the answer to our question; the building mentioned there was part of the religious space of the people who built it.

The ancients' religious domain consisted of the temple pyramids and ceremonial centers constructed on earth by their own hands. They were the center of their material existence and they dominated their life.² The domain of the gods was heaven and the celestial vault, epitomized by the natural order of the cosmos. But heaven and earth are connected since humans, cast in the image of their gods, are guided by heavenly forces. The king's center of worship becomes a replica of the dwelling of his god. The penetration of the forecourt through the sanctuary to the inner shrine on a two-dimensional surface is equivalent to the ascent of the king to progressively higher levels of heaven in the third, or vertical, dimension.

Not only the temples but also the rituals dramatized within them connect the imperfect earthly realm with the unattainable divine. Paul Wheatley (1971), in discussing the spatial arrangement of buildings in the Chinese city, suggests that those religions which specifically associate the creation of the universe with the origin of mankind usually

dramatize the cosmogony by attempting to reproduce on earth a miniaturized version of the cosmos. On the other hand, those which relate divine revelation to the meaning of human existence abstract their gods from the landscape, and the attendant rituals appear to bear little connection to the environment. Thus, in eastern Asia and, particularly, in Mesoamerica, where creation hypotheses are heavily mythologized, we can expect religion to have played a decisive role in the planning of ceremonial centers. We recall from Chapter IV that the Maya Long Count reckoned all temporal events from the start of the most recent creation epoch 4,000 years in the past.

Theologian-historian Mircea Eliade (1958), also interested in a comparison of world religious systems, gives an account of cosmic hierophanies, which he defines as "the sacred revealed at different cosmic levels" (p. xiii). His discussion of architectural hierophanies emphasizes the cohesive bond between ancient religion and cosmology. The choice of a place to build the sacred capital is determined by processes originating in a complex system of cosmological beliefs. The divine nature of the place chosen to erect a holy city may be revealed through certain signs obtained from heaven or on earth—the direction of the magnetic compass, the presence or absence of certain plants or animals, the passage of a particular celestial body across the zenith. The consecration of the holy place, once having been revealed, evokes the creation myth by a re-enactment of it, as for example in the construction of the Vedic altar of sacrifice. As theologian Alfred Jeremias explains:

The consecrating of the spot followed a twofold symbolism. On the one hand, the building of the altar was conceived as a creation of the world. The water with which the clay was mixed was the same as the primeval waters: the clay forming the altar's foundation, the earth; the side walls, the surrounding atmosphere and so on. On the other hand, the building of the altar was a symbolic integration of time, its "materialization in the very body of the altar." The altar of fire is the year. . . . The nights are the stones surrounding it and there are 360 of them because there are 360 nights in the year; the days are the yajusmati bricks, for there are 360 of them; and there are 360 days in the year." The altar thus becomes a microcosm existing in a mystical space and time quite distinct in nature from profane space and time. To speak of building an altar is, in the same breath, to speak of a repetition of the creation of the world. (1929, pp. 9–11)

In order to duplicate the heavens in their earthly environment, the ancients found it necessary to know the way of the wanderers who populate that realm. The representation of the length of the tropical year as 360 days, though inaccurate by our standards, reveals an attempt on the part of early humans to know in advance how their gods would behave. In our modern scientific attempts to understand the natural world, we also seek to attain a predictive advantage over nature, one which affords a measure of control over the environment. To accomplish this task we employ complex instrumentation to extend

our senses and a rigorously defined formal system of logic, often, some would say, under the pretense of glorifying nature for its own sake. But are the thought processes of modern people, though more complex, very far removed in basic structure from their ancestors' form of thought?

Historian of Old World science A. Aaboe (1974) recognizes two levels of prescientific astronomy: the less advanced level, characterized by the naming of fixed stars and planets and recognition of the difference between the two, the recognition of morning and evening stars as different aspects of the same body, and the use of heliacal risings as seasonal indicators; and the more advanced level, which employs mathematical cycles of varying degrees of complexity in dealing with the periods of the major bodies of the solar system. These periods are employed to predict astronomical events, and in advanced civilizations they supply information which may serve as a basis for formulating models of the universe. Following the historical development of Babylonian astronomy, he regards an astronomical theory as "scientific" only when it can be formulated as "a mathematical description of celestial phenomena capable of yielding numerical predictions that can be tested against observations" (p. 21). We shall see whether the Mesoamerican priest-astronomer lives up to the Western definition of a scientist and how important his fulfillment of that quality might be.

Recognizing the close marriage between religion and astronomy, in this chapter we seek to determine the extent to which architectural planning and orientation in the Mesoamerican landscape constituted astronomical prowess. Even at the simplest level we will recognize that the seeds of science are being sown. But we must be careful about using our own cultural yardstick to judge the intellectual skills of others. One's astronomy must remain fixed within the cultural framework that spawned it.

Since the flow of heavenly motion pivots about the north-south axis, we should expect to find the earliest settlers orienting their cities on the cardinal directions to reflect the harmony of the world.³ Here we straddle the thin line between cosmic geomancy (divination from magical signs obtained from earth and sky) and true functional astronomical orientation. When city planners became more sophisticated in the precise establishment of the cardinal directions and began to make use of an extensive grid pattern with associated markers along the horizon to determine precise periods in the calendar, they left the religious level and entered into scientific pursuits. Cosmic geomancy was transformed into true astronomical orientation, and the city became a functioning astronomical instrument. When finally the periods were tabulated and synthesized for the purpose of predicting celestial cycles, such as phases of the moon, retrograde motion, and eclipses, the predictor must be regarded as considerably advanced intellectually. From our discussion of Mesoamerican calendars in Chapter IV we know that a great pinnacle of achievement was reached in preconquest days.

The study of the relationship between positional astronomy and the planning and arrangement of buildings is termed astroarchaeology, particularly when such studies require and utilize orientational data from the remains of ancient cities. These pursuits can become compli-

cated and often they produce uncertain results, for in addition to religious and astronomical considerations, we must recognize that the location and orientation of a building may be influenced by a combination of several other factors, among them pure chance, aesthetics, topography (both natural and artificial), climate (direction of prevailing sun or wind), water supply, and the need for military defense.

To comprehend the depth of knowledge of positional astronomy in ancient Mesoamerica, we begin by considering the role of astronomy in the overall plan of the Mesoamerican city and ceremonial center. Later we examine individual structures possessing peculiar shapes and/or orientation to see whether their unorthodox design might have served an astronomical purpose. We include a brief discussion of the recognized astronomical hierophanies, for in some centers, particularly Palenque, these may have played a decisive role in the determination of the location of the most important monuments. Finally, for purposes of comparison, we review a few cases of astronomical orientation among the adjacent civilizations of North and South America.

Given the preoccupation of the Mesoamericans, and particularly the Maya, with matters of calendar, mathematics, and astronomy and considering the suggestions in the codices that astronomer-priests may have used the doorways of special star temples to make their observations, it is surprising that the subject of building orientation, until quite recently, had received little attention. Most of the early discussions of the problem in the literature are based upon data gleaned from inaccurate site maps. In particular, the direction of true north on many maps often is laid out erroneously; frequently, it is confused with the orientation of the needle of the magnetic compass, and in many cases the reader is not told whether a correction to adjust magnetic to true north has even been applied. When such an adjustment is made, often through the use of outdated magnetic declination tables, the accuracy of the result is still questionable because the direction of the magnetic compass pointer varies over a relatively short time period. Some of the pitfalls associated with the procurement of accurate astroarchaeological data are outlined in Appendix B of Chapter III. ✧

Architect Horst Hartung (1975, pp. 193–200) has listed some logical architectural schemes, or clues, for recognizing base lines of possible astronomical interest in archaeological remains:

- (a) Lines traced with paint or carved on stone or the stucco which usually covers the stone.
- (b) A vertical surface or the edge of a window or door as viewed from a fixed point.
- (c) Horizontal and vertical shafts.
- (d) Lines between sculptured elements.
- (e) Unusual architectural arrangements in a building or a group of buildings.
- (f) Artificial or natural elements of a distant landscape.
- (g) Lines drawn perpendicular to the doorway or façade of a building. These lines, once astronomically determined, can be used to specify the location of other buildings.

We will see examples of all these schemes in the case studies reported in this chapter.



FIG. 67. Teotihuacán, Mexico, largest of all ceremonial centers in Meso-america.

THE PLANNING AND ORIENTATION OF MESOAMERICAN CEREMONIAL CENTERS

The rectangular plan dominating Teotihuacán, the largest and most famous of all ceremonial centers of ancient America, is both grandiose and precise (Figs. 67 and 68). Here, the architecture exhibits an ordered harmony which surely finds its roots in the cosmos. The Pyramid of the Sun forms a projecting volume which is counteracted by the four-sided concave form of the Ciudadela (Citadel): positive and negative spaces seem to balance one another. A line passing from the summit of the pyramid parallel to the principal north-south axis of Teotihuacán (called the Street of the Dead by the later Aztecs) crosses the exact geometric center of the Citadel. The smaller buildings aligned along this ceremonial way are perfectly fitted to the grid structure.

But the orientation of the city, which the builders evolved a few centuries before the Christian era, seems to defy the local topography. Once ordained, every part of the environment seemed forced to conform to it. The course of the Río San Juan and its tributaries was modified to fit the plan. In the map of the ruins in Fig. 68 we see the river entering at the northeast, performing several angled bends as it becomes canalized while passing through the center, finally exiting on its natural course toward the southwest. This grid orientation must have been of extreme importance because the Teotihuacán architects re-

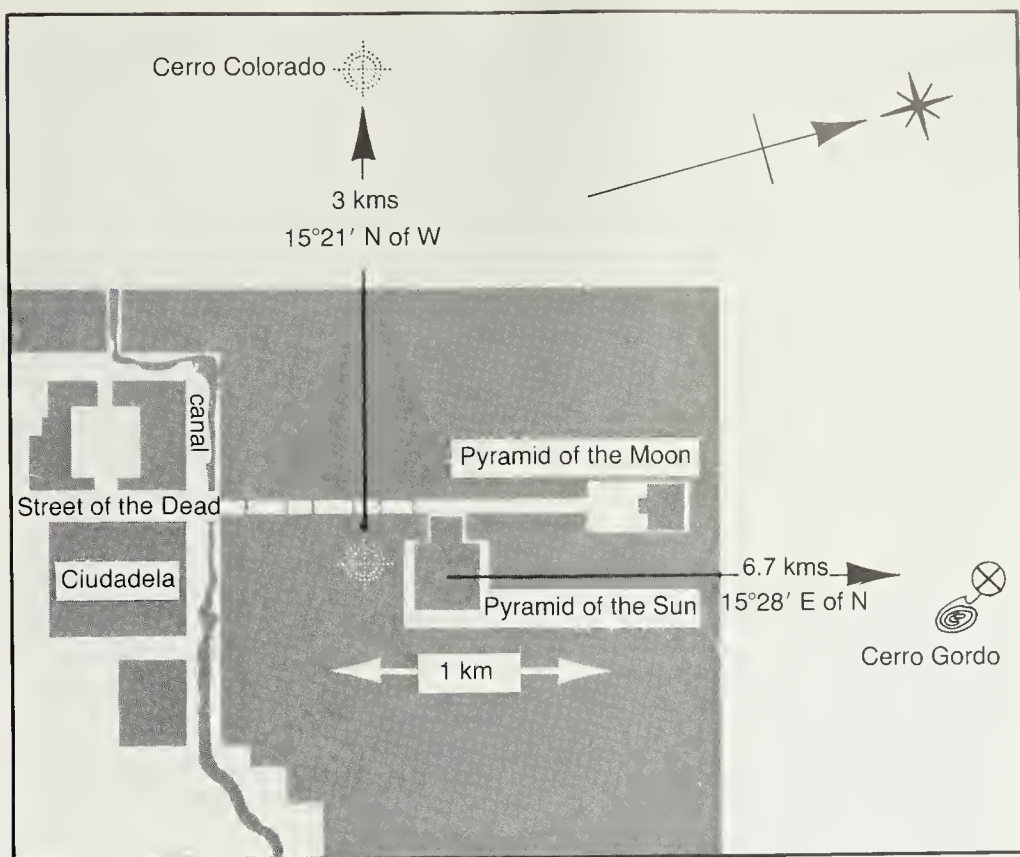
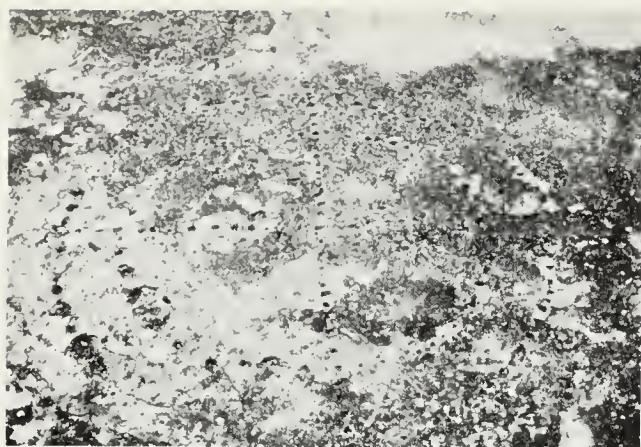


FIG. 68. Plan of Teotihuacán showing the positions of its principal structures and three of the pecked-cross petroglyphs which may be related to the precise grid plan. (Diagram by P. Dunham)

tained it with great precision even in the hillside barrios on the outskirts of the ceremonial center. While it would have been simpler and more expedient to deviate from the plan by adding buildings where the natural environment dictated, the Teotihuacanos chose instead to follow the predestined design. Indeed, the overall appearance of the city suggests that its designers left little to chance.

As Millon (1973) and his co-workers of the Teotihuacán Mapping Project have shown, the streets of the ancient holy city align in one of two directions, a north-south orientation $15^{\circ}28'$ east of north, which is exemplified in the map of Fig. 68 by the Street of the Dead, and an east-west orientation $16^{\circ}30'$ south of east. In Fig. 67 we look southward along the north-south axis from the top of the Pyramid of the Moon at the northern end of the ruins. The archaeological evidence suggests that the deviation of 1° from a perfect right angle between the two is probably not accidental. Many building complexes and residential compounds within the city follow the first orientation while others obey the second. Were the ancient architects resisting the local topography for astronomical reasons?

A clue to the motivation behind the basic orientation may be found in a curious marker pecked into the plaster floor of one of the buildings adjacent to the Pyramid of the Sun near the center of the city. It consists of a pair of concentric rings centered on a cross and may



a



b



c

FIG. 69. Three pecked-cross petroglyphs: (a) marker adjacent to the Viking Group near the Pyramid of the Sun at Teotihuacán; (b) cross on Cerro Colorado, 3 kilometers to the west of the marker in (a); (c) a nearly identical design 720 kilometers north of Teotihuacán near Durango, Mexico.

have functioned as a surveyor's mark for the city planners. About a meter in diameter and consisting of holes spaced a few centimeters apart, the pattern is still visible to visitors as it lies unprotected (Fig. 69a). Three kilometers to the west on the slope of Cerro Colorado, workers of the Teotihuacán Mapping Project discovered another carving of similar size and shape on a small rock outcrop (Fig. 69b). Viewed from the first marker, the outlying petroglyph has a bearing of $15^{\circ}21'$ north of west. Thus an east-west base line connecting the crosses lies within 7 minutes of arc of a perfect right angle to the Street of the Dead. Fig. 68 schematically illustrates the curious relative placement of the two crosses. Does the coincidental placement of the cross pet-



FIG. 70. View of the western horizon of Teotihuacán as seen from the pecked cross near the Viking Group.

roglyphs mean that the Teotihuacanos employed the base line as part of a grand scheme in laying out the Street of the Dead? The architects clearly possessed a vision of the plan of the city and the high degree of order they would impose upon the landscape well in advance of the first stages of construction. In the process they found it necessary to construct a very accurate right angle—deviating by less than 10 meters from a straight line over 3 kilometers long.

Next we ask: Does this east-west base line coincide with a significant astronomical event occurring on the local horizon? To test this hypothesis, one must determine for the latitude, building time, and horizon elevations of Teotihuacán which astronomical bodies could have been viewed along either direction. Of the few possibilities which fit the conditions, the most reasonable seems to have been the Pleiades.⁴ Fig. 70 is a simulated view (reconstructed with the aid of a planetarium) of the western horizon of Teotihuacán as viewed from the first petroglyph. The Cerro Colorado marker is located by an arrow in the figure. The stars appear in their exact positions relative to the horizon about A.D. 150, when we believe the grand plan of the ceremonial center was conceived. The Pleiades are the conspicuous group situated above the arrow; they set with 1° of the line between the pair of crosses.⁵ In addition to closely matching the alignment, this star group functioned in a most unusual way at Teotihuacán at the time the city was constructed. The Pleiades underwent heliacal rising on the same day as the first of the two annual passages of the sun across the zenith, a day of great importance in demarcating the seasons. Readers who wish to approximate this fact should consult Tables 3, 10, and 11. The date is approximately May 18. The appearance of the Pleiades served to announce the beginning of this important day, when the sun at high noon cast no shadows. Furthermore, the star group itself also passed close to the zenith of Teotihuacán.

In view of both the coincidence of events and the central impor-

tance of this group in Mesoamerican star lore (see Chapter II), the Pleiades must be regarded as the most likely astronomical source for the curious orientation of Teotihuacán, though alternate hypotheses have been proposed (e.g., Malmström, 1978).

A third marker on the outskirts of the city also may have figured in the plan. Another cross petroglyph design is located about 7 kilometers north of the Pyramid of the Sun, near the summit of Cerro Gordo, the most prominent elevation on the Teotihuacán landscape. This cross is a line carving situated on a prominent rock outcrop; attached to the design we can see another carved figure resembling a serpent.

The Cerro Gordo cross can be viewed directly from the cross near the Pyramid of the Sun. A measurement of the orientation between the two seems only to add to the mystery. The line between them points 17° east of astronomical north—almost exactly perpendicular to the major east-west street. Recall that the east-west axis of Teotihuacán is *not* perpendicular to the north-south axis. Dubhe, the brighter of the pointer stars of the Dipper, could have served as the stellar reference for this direction; the unusual geometry is depicted in Fig. 68.⁶ On the other hand, if the center of the Pyramid of the Sun were used as the sighting point, the orientation turns out to be $15^\circ 54'$, or just 50 meters out of line with the axis of the Street of the Dead and the orientation of the Pyramid of the Sun itself.

Other pecked designs, many of a cruciform nature, have been discovered at Teotihuacán,⁷ and more recent studies have revealed that the use of these cross markers had spread to the remotest limits of the Teotihuacán empire. To date, over thirty examples, carved in rock outcrops and in the floors of buildings, have been mapped, measured, and photographed (see Figs. 69 and 71 for photographs and rubbings of some of them).

Five crosses of identical design along with a few associated petroglyphs can be found near the pyramid of Tepeapulco, about 30 kilometers northeast of Cerro Gordo. One of them has its axis pointing in the direction of Cerro Gordo. But the most remarkable occurrence of the cross petroglyph design occurs far north of the Teotihuacán valley. A pair of pecked crosses nearly identical to the Teotihuacán cross was found by University of Southern Illinois archaeologist J. C. Kelley (1975) at Alta Vista, an archaeological site possessing strong Teotihuacán influence in Zacatecas state on the northern frontier of Mexico. His Chalchihuites ceramic studies had already indicated an intense preoccupation of the people with the idea of quartering the world, with gods in each quadrant. These were often accompanied by star representations; Kelley also discovered a temple at Alta Vista with corners pointing to the four cardinal directions. X

The pair of cross markers, which he regards as "bench marks," was located on Cerro El Chapín, an elevated plateau south of the site. They lie within 10 kilometers of the present Tropic of Cancer (latitude $23^\circ 27' N$) where the sun attains the zenith only on the day of the summer solstice.⁸ The axes of the petroglyphs point in that general direction. Because of the strong Teotihuacán influence in the Alta Vista architecture and the remarkable resemblance of the Chapín and Teotihuacán cross-circle patterns, Kelley has proposed a fascinating hypoth-

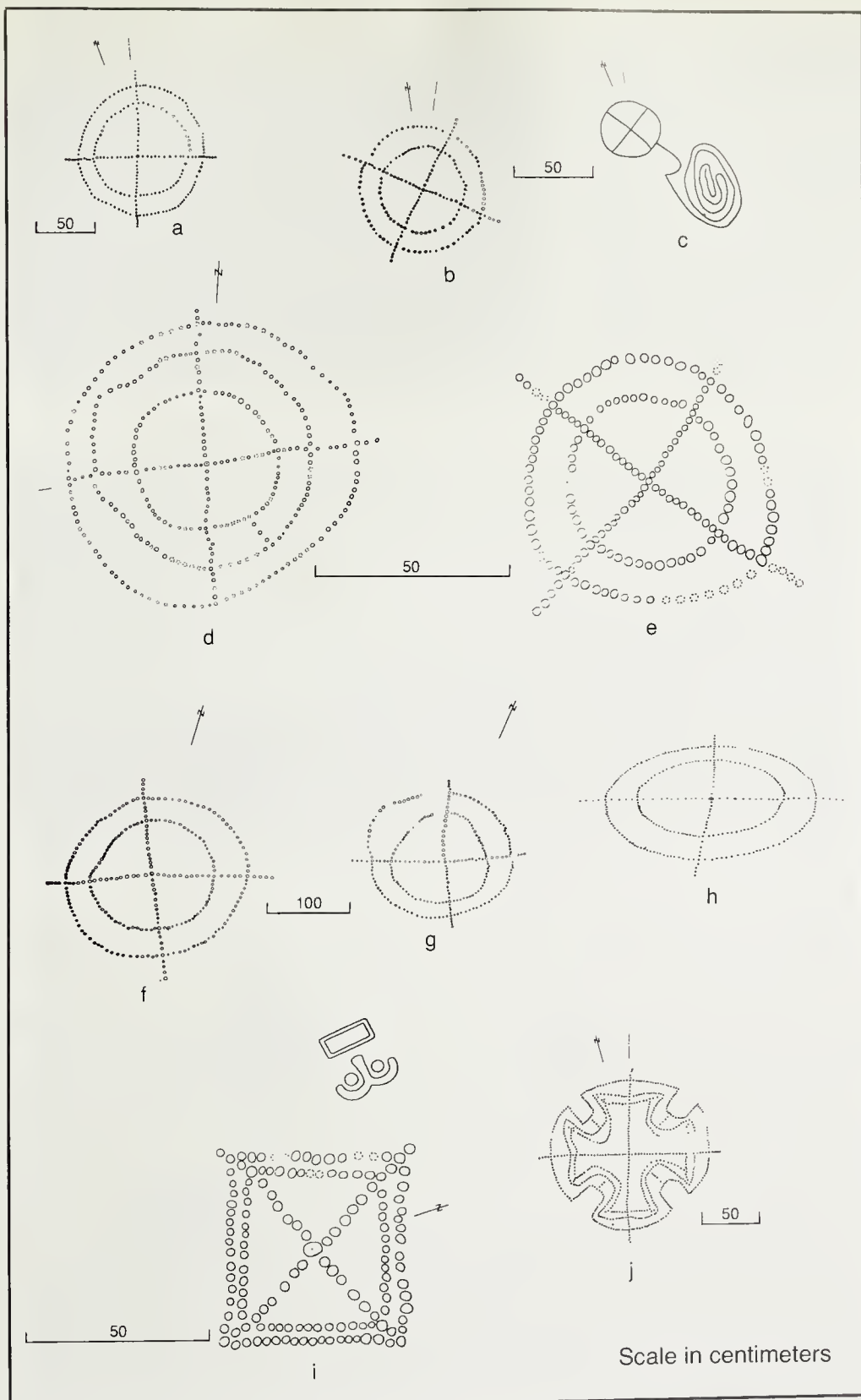


FIG. 71. Diagrams of pecked crosses obtained from rubbings: (a) cross adjacent to the Viking Group, Teotihuacán; (b) Cerro Colorado, Teotihuacán; (c) Cerro Gordo, Teotihuacán; (d) Tepeapulco, petroglyph no. 1; (e) Tepeapulco, petroglyph no. 2; (f) Cerro El Chapín, petroglyph no. 1; (g) Cerro El Chapín, petroglyph no. 2; (h) cross pecked into the floor of Structure A-V, Uaxactún; (i) Tlalancaleca, one of three pecked square petroglyphs; (j) large Maltese Cross carved in the floor of a building at Teotihuacán.

esis to explain how the cross design migrated hundreds of kilometers northward.

He suggests that Teotihuacán priest-astronomers must have been searching for the place "where the Sun turned" (as the Pueblo Indians would say); they located the approximate area and then surveyed in the location of Alta Vista from Cerro Chapín, placing it so that the mountain calendar enabled easy determination of the summer solstice for use in checking the location of the Tropic. Then they laid out the initial building unit (incorporating magical calendrical features in its architecture), oriented with corners to the cardinal directions, as a temple for Tezcatlipoca in his capacity as lord of the four directions and of the nocturnal sky. Notably, later buildings at Alta Vista (after A.D. 300 or 400) shifted to a new orientation.

But the arrangement is still more complex. Recently Kelley noticed that a viewer standing in the Temple of the Sun at Alta Vista will witness the sunrise at the equinoxes in a due easterly direction. The event takes place over Cerro El Chapín, the most prominent natural marker on the horizon and the summit above a rather extensive turquoise mine. Does this suggest that the location of Sun Temple was deliberately determined so that one could permanently register the equinoctial sunrise in the landscape? Shifting his location 7 kilometers to the south, Kelley witnessed a sunrise over the same peak precisely at the June solstice. In this instance the pecked circle seems to have functioned as a sun watcher's station. It is possible that a similar circle was positioned north of the Alta Vista ruins to mark the sunrise at the winter solstice. The situation is mapped out and documented photographically in Fig. 72. There is a feeling among archaeoastronomers that this outpost of Teotihuacán civilization has not yet yielded all its astronomical secrets. At both Teotihuacán and Alta Vista we find a functional relationship among an astronomical alignment, the orientation of a ceremonial center, and a pecked cross symbol.

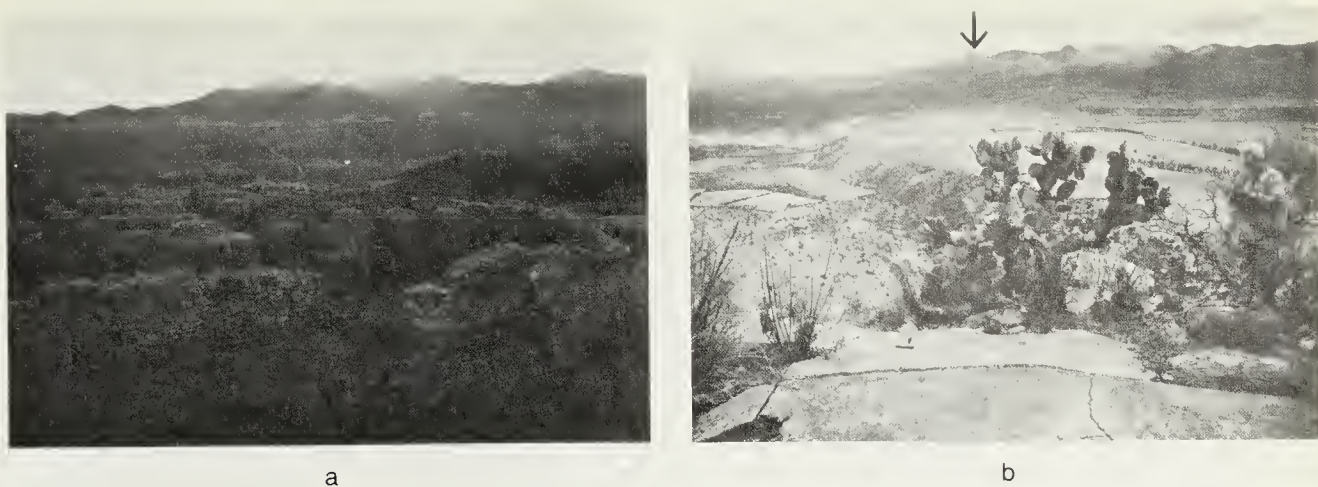
In addition to a handful of designs at more remote ruins in Central Mexico, other cross petroglyphs of undeniably similar style and execution survive at the other end of the Teotihuacán empire. Three markers in the southwestern corner of the floor of Structure A-V at the Maya city of Uaxactún, Guatemala (Fig. 71*h*), may predate the Teotihuacán crosses.

When we assemble the data on cross petroglyphs found across Mesoamerica, a body of useful descriptive facts begins to emerge:

1. General form: Usually the design has the shape of a double circle centered on a pair of orthogonal axes. In a few cases the circle is single or triple. Rarely, the double circle is replaced by a double square (Fig. 71*i*) or the circular patterns take the form of two-dimensional crosses (Fig. 71*j*).

2. General setting: Of the 40 designs studied, fewer than half are pecked into the floors of buildings (three at Uaxactún, eight at Teotihuacán). The remainder are carved on rock outcrops, most of which offer panoramic views of the horizon, usually to the east.

3. Mode of execution: All but two crosses were created with some sort of percussive device. The cuplike depressions constituting the design average 1 centimeter in diameter and are spaced 2 centimeters apart.

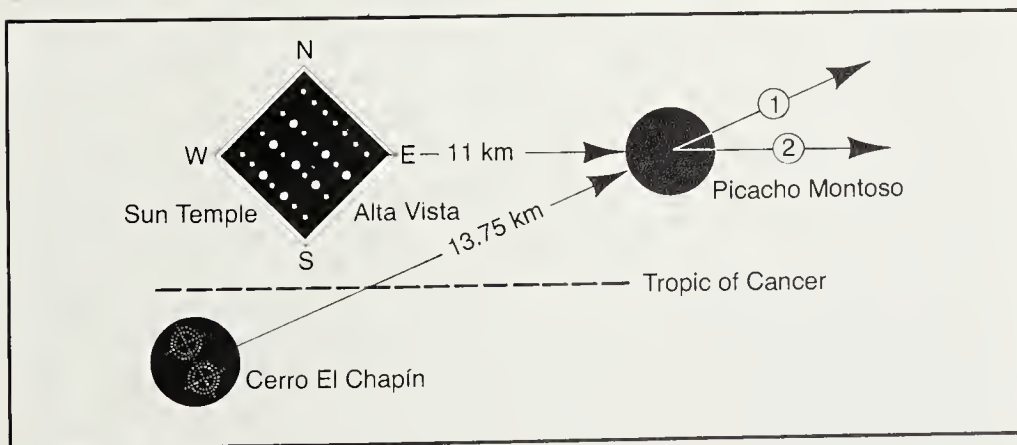


a

b



c



d

FIG. 72. (a) The equinox sunrise viewed over Picacho Montoso from the ruins of Alta Vista in northwest Mexico; (b) the summer solstice sun rises over the same prominent peak when viewed from the petroglyphs on Cerro El Chapín, 7 kilometers to the south of Alta Vista (courtesy of J. C. Kelley); (c) the same scene as in (b) from El Chapín taken on the morning of June 21, 1979, showing the peak illuminated by the rising sun; (d) schematic view of Alta Vista and vicinity illustrating the unique double solar alignment (1) from the pecked crosses to the summer solstice sunrise and (2) from the Sun Temple to the equinox sunrise (diagram by P. Dunham). It may be significant that these astronomers did their sunwatching at the Tropic of Cancer.

4. Orientation of axes: The axes of the crosses located along the Street of the Dead align with the Teotihuacán grid, and those at Uaxactún seem to have been intended to match the orientations of its buildings. A few of those located outside ceremonial centers, particularly those in northwest Mexico, exhibit a tendency to point in the general direction of the rising or setting points of the sun at the solstices. The axes of certain petroglyphs exhibit marked deviations from a right angle which may have been deliberate (they can be spotted easily in Fig. 71). The axes of the three northernmost crosses are oriented to the summer solstice sunrise position, a common orientation direction which many investigators are beginning to turn up in North American astroarchaeological investigations. Evidently, the turning points of the sun begin to take on greater significance as one moves out of the tropics, perhaps because the migration of the sun along the horizon becomes more pronounced as one moves toward the higher latitudes (Fig. 25 illustrates this principle).

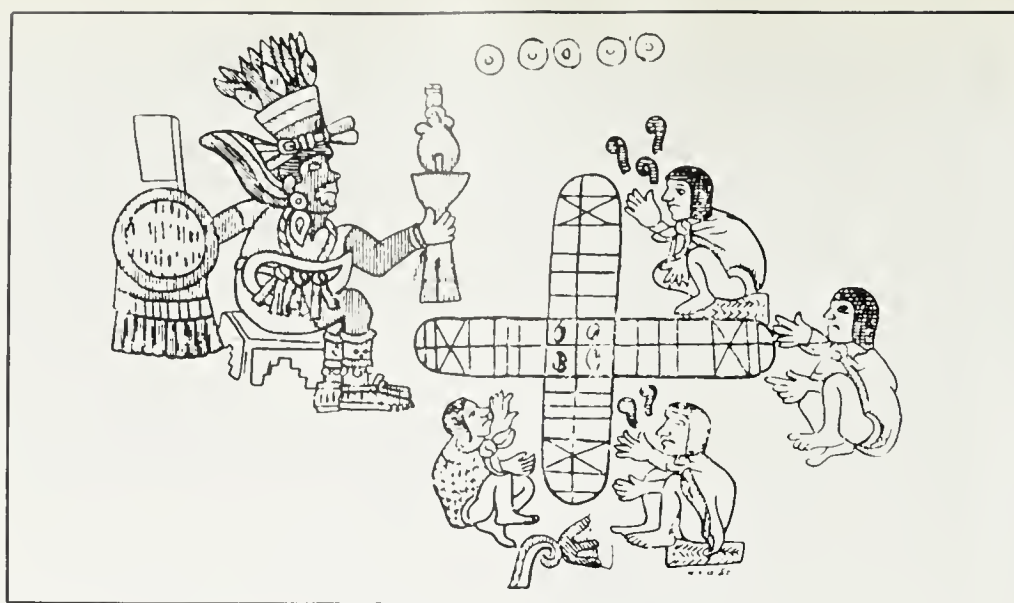
5. Orientation between crosses: The pair of petroglyphs at Teotihuacán seem to have functioned as architects' bench marks with respect to that ceremonial center. Possibly we can say the same for the crosses near the Tropic of Cancer and those at Tepeapulco. In these cases a significant cross-to-cross or cross-to-site alignment exists. These long-distance base lines may have resulted from astronomical motives, such as the desire to align the markers with the position of appearance or disappearance of an important astronomical body on the local horizon.

6. Numerology: A remarkably consistent pattern among 80 per cent of the petroglyphs concerns the placement of the holes on the axes. Usually one finds ten dots between the center and the first circle, four dots between the inner and outer circles, and four dots beyond the outer circle. If we count as axial holes those marking the intersection of an axis with a circle, then we have the pattern $10 + 1 + 4 + 1 + 4 = 20$ rather than $10 + 4 + 4 = 18$. Both numbers are important in the ancient Mesoamerican calendar. In three cases the total number of holes in the entire pattern is 260, and in a number of cases portions of the pattern add up to that important number. For example, the 260-day calendar cycle may be related to the pattern of pits counted on the periphery of the Teotihuacán No. 2 cross depicted in Fig. 71*j*. Found in the floor of a building along the Street of the Dead, this triple concentric design takes the shape of a Maltese Cross. Though portions are badly eroded away by years of exposure to sun and rain, enough is left to yield a true picture of what the artist probably intended. A tally of twenty holes between the axes and vertices of the outer pattern has been observed, while double thirteens occur in each indentation midway between the cross arms. Thus, beginning at an axis by counting one for each of the points on axis and one for each point at the vertices of the two-dimensional cross arms, we have the count $1 + 18 + 1 + 13 + 13 + 1 + 18 + 1 + 18 + 1 + 13 + 13 + \dots = 260$.

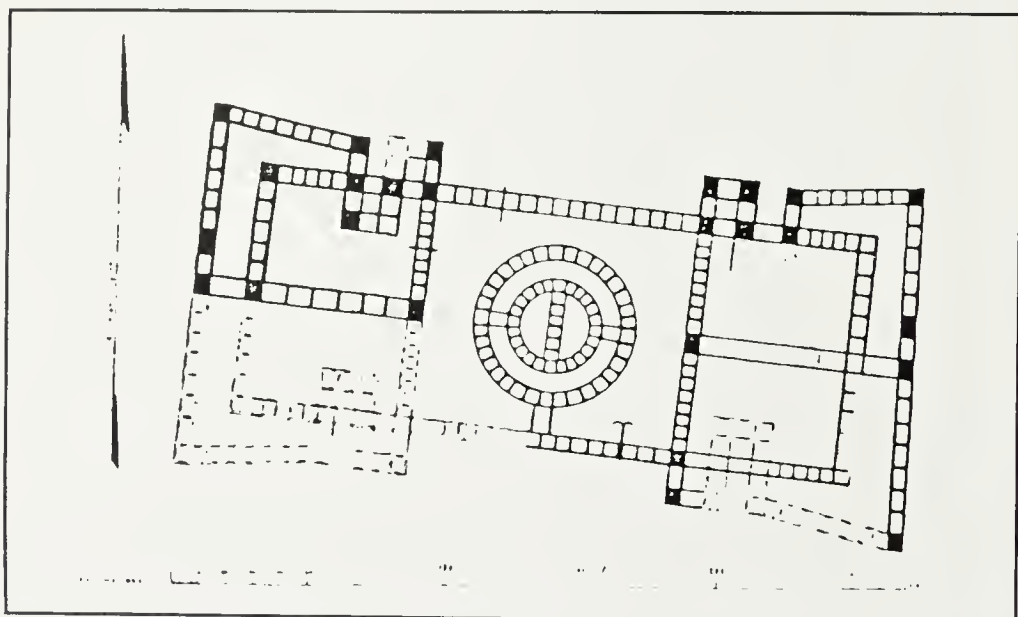
The pattern exhibited by this elaborate petroglyph invites a direct comparison with the pair of calendric diagrams from the codices discussed in Chapter IV (Figs. 57*b* and 57*c*). The arrangement of points representing the 260-day count on the periphery of these diagrams is virtually identical to that on the Maltese Cross petroglyph.

We recall that the Mesoamerican cosmic view embodied in those textual diagrams encompassed a multivariate interpretation of the calendar, a characteristic not unlike that which the modern relativists employ when they unite time to space in describing the large-scale universe. Are space and time also locked together in the symbolism of the cross petroglyph? If we are willing to believe that design patterns in the literature bear a distinct resemblance to the quartered-circle petroglyphs, then it should not be so surprising to find evidence in the examination of the petroglyphic data which permits not only orientational but also numerical interpretations.

The evidence for a hidden likeness between cross petroglyphs and calendar wheels, in fact, seems quite specific. The axes of several cross petroglyphs correlate very well with solstice positions, and a solar symbolism is strongly suggested by a spiked fringe pattern found between concentric circles on two of the symbols. In the case of the Teotihuacán crosses, axial direction seems to have been modified to fit the overriding architectural plan. Evidently, "Teotihuacán north" was more important than astronomical north, at least important enough to warrant marks on the floors of buildings. The environment of many of the crosses seems to have been chosen because of the advantage for long-distance unobstructed observations, either of heavenly bodies near the horizon facing the site or of other markers, signs, or perhaps ceremonial centers in the adjacent landscape. The dualism attached to the significance of the pecked crosses is further enhanced by noting the resemblance between these designs and the Aztec religious game of *patolli*. Fray Diego Durán, writing shortly after the conquest, gives this description: "Another game was played as follows. *Small cavities were carved out of a stuccoed floor* in the manner of a lottery board. Facing each other, one [player] took ten pebbles, and the other [also took] ten. The first placed his pebbles on his side, and the other on his. Then they cast split reeds on the ground. These jumped, and those that fell with the hollow side face upward indicated that a man could move his pebbles that many squares. Thus they played against one another, and as many as a player caught up with he won, until he left his opponent without chips. Occasionally it happened that, after five or six [pebbles] had been taken, with the four remaining ones the reeds were also bet, together with the others, and thus the game was won" (1971, p. 302; italics added). By Aztec times these devices were cross shaped and the players moved beans over a pecked surface or over a painted mat. In at least one form of the game played in the southwest, a circle consisting of ten pits per quadrant was employed. As the depiction of the playing surface in Fig. 73a suggests, the game bore a distinct resemblance to the East Indian game of pachisi. The principal feature of the board was an "X," or cross, undoubtedly symbolizing the four directions. Frequently, the board was divided into 52 or 104 divisions and the player moved markers from point to point on the board. Dried beans were painted with numbers representing the value of the number of points to be advanced. According to Durán: "If the painted number was five, it meant ten [squares]; and if it was ten, it meant twenty. If it was a one, it meant one; if two, two; if three, three; if four, four. But when the painted number was five, it meant ten, and ten meant twenty. Thus those small white dots were indicators and showed how many lines



a



b

FIG. 73. (a) The game of *patolli* as represented in the Codex Magliabecchiano (XIII, f. 60), a conquest-period document. Four players engage in the contest while the god Macuilxochitl, who symbolizes the game, looks on. The pecked crosses may have represented an alternate form of the *patolli* playing surface. (b) *Patolli* board painted on the floor of a Huastec building in Tampico, Mexico (Muir, 1926, p. 237; courtesy of Royal Anthropological Institute of Great Britain and Ireland).

could be passed while moving the pebbles from one square to another" (p. 303). The grouping of numbers in units of 5, 10, and 20 bears a distinct connection to the arrangement of cuplike depressions on the axes of the pecked crosses. If we include in the count the intersection of the axes with the circles, then our tally becomes $10 + 1 + 4 + 1 + 4$ or $10 + 5 + 5$.

Two paintings of the *patolli* board can be seen on the floors of Huastec buildings on the Gulf Coast of Mexico (Fig. 73*b* shows one of them). Though quite different from the *patolli* board pictured in Fig. 73*a*, they exhibit a remarkable resemblance to the Teotihuacán crosses. Not only do they occur in the same architectural context (the floors of buildings) but they also consist of double circles, the axes of which appear to be aligned with or skewed slightly from the cardinal directions. Exposures of the underlying stucco floor, where they were discovered, revealed similar painted designs from an earlier phase of the Teotihuacán-related culture.

Whatever relationship they bear to Teotihuacán orientation, the widespread cross petroglyph carvings cannot be dismissed as mere symbols. A single hypothesis cannot account for their origin—they must be tied to calendar, alignment, and religion all at the same time. Furthermore, the propagation of such universal symbolism is to be expected in the development of a state.

Still another astronomical hypothesis for the orientation of Teotihuacán has been suggested by anthropologist David Drucker (1979) of the Teotihuacán Mapping Project. He believes that local topographic features along the Teotihuacán horizon may have been a determining factor and that the ritualistic 260-day cycle also was involved. More than a thousand kilometers southeast of Teotihuacán lies the Maya city of Copán, where the 260-day calendar is believed to have originated. From our discussion of the possibilities regarding the origin of the 260-day cycle in Chapter IV, it will be recalled that at Copán the sun transited the zenith on April 30 and, 105 days later, on August 13. It spent the remaining 260 days of the tropical year in the southern part of the sky. For the people of Copán, the division of the year into two unequal parts may have served a very practical function since the 105-day period constituted a planting season with a beginning that any observer could determine quite simply. Drucker hypothesizes that the Teotihuacanos adopted the Maya calendar and incorporated it into the design of their city. But the Teotihuacán solar zenith passage dates are May 18 and July 24, only 67 days apart—too short for a planting season. Thus, in order to accomplish their feat, they located the principal structures of their city so that the sunset positions on the two Copán zenith dates would coincide with conspicuous natural landmarks observed from the buildings along their local horizon. After the monuments were erected, corrections to the original alignments were necessary in different parts of the city, since the horizon perspective as viewed from the tops of the pyramids would appear slightly different from that viewed by an observer at ground level. The slightly different orientation groupings we measure at Teotihuacán today resulted from the execution of these corrections. Thus, even though the Sun Pyramid priests were far from the place where their sacred calendar originated, they could still keep track of the important divisions in the 260-day cycle.

A large part of Drucker's argument rests on his ability to recognize conspicuous landmarks along the horizon as well as to establish Maya contacts in the Teotihuacán valley at a very early date. While it is true that the sun sets in a saddle (the shallow depression visible to the right

of the Pleiades in Fig. 70) between two hills on the horizon on the day of Copán zenith passage, there are many conspicuous elevations and depressions in the landscape, and the one he uses may be in no way outstanding.

Among the nonastronomical factors contributing to building placement and orientation at Teotihuacán we must include the suggestion of Doris Heyden (1975) of Mexico's Instituto Nacional Antropología e Historia. She believes that the placement of the Pyramid of the Sun, the city's major building, was determined by the location of a multichambered cave recently discovered beneath it. The center of the pyramid is located nearly above the center of the cave and a line from the center to the mouth of the cave coincides closely with the east-west axis of the pyramid. Many historical references allude to a number of cave deities in Central Mexico.

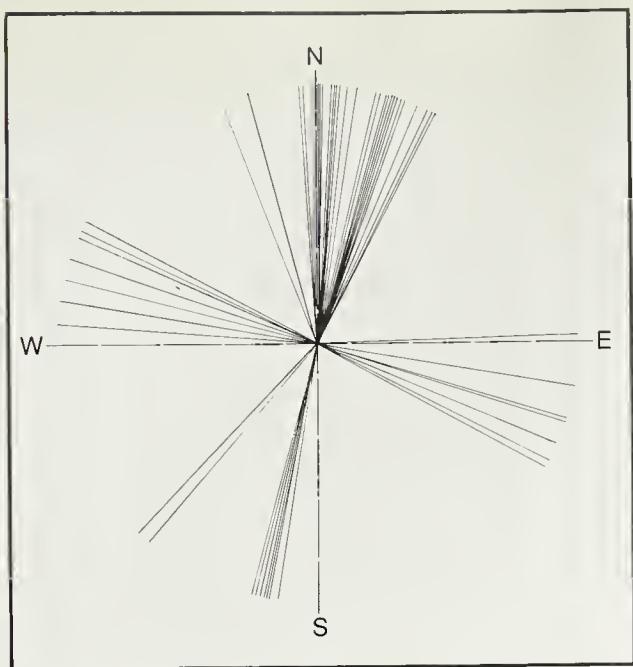
As Heyden points out, even in the consideration of alternate hypotheses we still should not overlook the astronomical possibilities. She has suggested that the cave may possess a symbolic significance which relates to astronomy; for example, a sixteenth-century historian writing about the grotto at Teotihuacán states that "another [god] went into a cave and came out of it as the Moon" (p. 142).

Still another investigator, Stephen Tobriner (1972), has proposed that Cerro Gordo, the principal source of water for Teotihuacán, determined the layout of the city. Because this mountain was so important for the local inhabitants, they simply oriented their main road toward it. (The road actually points 2° to the west of the summit.)

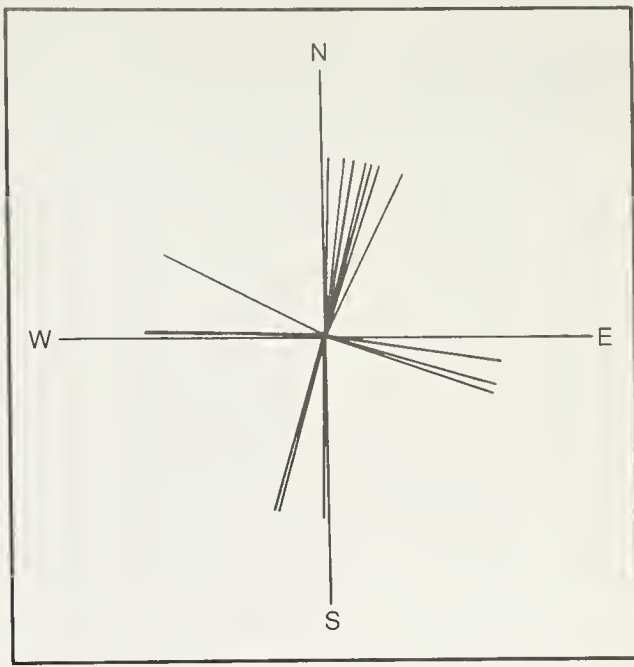
Fig. 67 reveals a similar subtle topographic relationship between Teotihuacán and its environment, one often noticed by visitors to the ancient city. Viewed from the Pyramid of the Moon at the north end of the city, the Pyramid of the Sun stands silhouetted against the background of Cerro Patlachique in the distance, the stepped façade of the pyramid imitating elevations in the natural environment. The pyramids seem to be the very image of the mountains which surround the Teotihuacán valley; it is as though they were created to visually reproduce the mountains.

Our discussion of the numerous hypotheses designed to account for Teotihuacán building orientations makes it clear that many factors, some of a practical, specific, and deliberate nature, others purely eclectic, must have contributed to the overall plan of the city. Scientific, religious, and magical elements of the Teotihuacán culture all influenced the grand design. They were fused in a way we find difficult to fathom. Our minds tend to dissociate the very cultural elements which brought the city plan together; consequently, we have difficulty understanding the full meaning of Teotihuacán architecture.

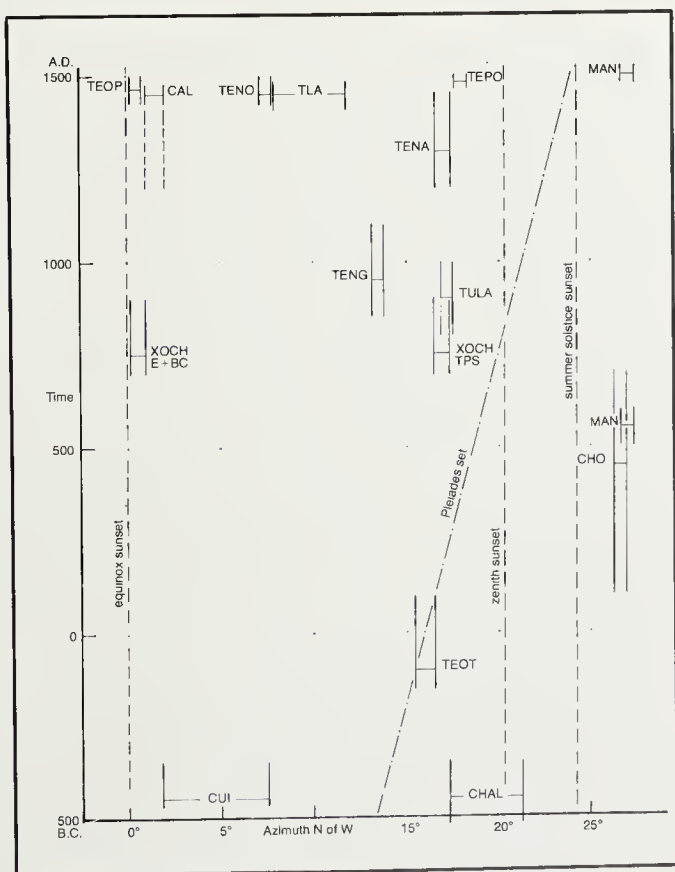
When we examine building orientation at other sites, a curious fact arises out of the assembled data: the clockwise deviation from true north exhibited in the axial plan of Teotihuacán seems to be shared by sites all over Mesoamerica. The polar graph shown in Fig. 74a illustrates the distribution about the cardinal points of well-defined major axes of sixty ceremonial centers. Appendix A contains an updated listing of alignments on major buildings determined by utilization of a surveyor's transit and astronomical fix. More than 90 percent of the



a



b



c

FIG. 74. Polar diagrams showing the orientations of the main axes of ceremonial centers: (a) all sites examined in Mesoamerica; (b) sites in Central Mexico only; (c) time-azimuth diagram for Central Mexican sites. Important astronomical directions are marked by dashed lines. Note the excellent match in space-time between the setting of the Pleiades star group and the east-west axis of Teotihuacán. (Diagrams by H. Hartung)

sites exhibit the clockwise skew and about 20 percent show the Teotihuacán orientation to within a few degrees (names of the latter sites are underlined in the table). At each site the orientations of the principal buildings were determined relative to an astronomical reference point, usually the sun, and the results were then averaged. Note the pronounced east-of-north trend—a single astronomical explanation cannot account for the spread in directions displayed in this diagram.

Can we analyze these data by looking for clusterings in orientation in both space and time? The rare handful of sites possessing a west-of-north orientation may be among the earliest in Mesoamerica. La Venta, the Olmec site situated in the Mexican state of Tabasco along the humid Gulf Coast, seems to be the archetype; it dates back to the first millennium B.C. The principal buildings in the ceremonial center possess a 6° to 8° west-of-north skew, but precise directions are difficult to determine since today the mounds are little more than dirt piles. The same general orientation occurs at Huitzo (about 2° or 3° W of N), another Olmec site located farther inland. The Poverty Point earthworks in Louisiana also possess this rare west-of-north orientation, possibly indicating an infusion of Olmec cultural elements.

Let us focus our attention on sites in the Valley of Mexico, where we have a large number of ruins in the samples. All fourteen sites examined there seem to exhibit great order in their layout. All are aligned east of north (Fig. 74*b*). In Fig. 74*c* we plot averaged site azimuth (with true east or west as zero) against estimated building time, ranging from 500 B.C. to A.D. 1500. The horizontal limits show the directional tolerance associated with the alignments; such uncertainties are attributed to the poor state in which we find some of the buildings. The vertical limits give the allowable error in our determination of the building time. We discover no strong trends in building direction from this diagram but, because all the sites are located in approximately the same latitudinal band, it is possible to derive useful information from the graph by adding lines showing the rise-set positions of astronomical bodies for a given horizon elevation (here assumed to be 3°). Thus, the Pleiades-set position intersects the Teotihuacán line precisely when the buildings were erected there, illustrating the astronomical orientation hypothesis discussed earlier. The equinox sunrise-sunset line intersects Xochicalco, and the alignments at Cholula and Manzanilla compare favorably with the solstice sunset.

The axis of the Cuicuilco pyramid, a structure with a circular base, is one of the earliest in Central Mexico. It shows a clockwise skew ranging from $1^\circ 43'$ to $7^\circ 38'$, depending upon which measurement can be accepted given the ruined state of the stairway bisecting the building. On the other hand, the Teopanzolco pyramid in Cuernavaca, one of the latest pre-Columbian buildings to be constructed, has its outer face skewed clockwise from the cardinal points by only $00^\circ 43'$. The face of the building appears to have been rather precisely oriented toward the equinox sunset position. At the ruins of Tlatelolco, now the Plaza of Three Cultures in Mexico City, the largest structure exhibits nine different building phases. The orientations range between $7^\circ 39'$ and $11^\circ 47'$ east of north but, again, no systematic variation in time is found to occur.

At some sites there may have been a conscious effort to preserve a particular alignment in spite of the intervening terrain. Two temples at Calixtlahuaca are good examples. They align nearly precisely in the same direction even though they are 100 meters apart and at different elevations; the measured axes are directed $1^{\circ}50'$ and $1^{\circ}12'$ south of east. With adjustments for horizon elevations the sun would rise along the axes of these buildings at the equinoxes. At other sites a conscious effort was made to distinguish different classes of orientations. For example, at Xochicalco all the buildings on the lower plateau are oriented $\frac{1}{2}^{\circ}$ east of true north, but the Temple of the Plumed Serpents, built on a higher, artificial platform, is skewed 17° east of north, possibly reflecting Teotihuacán influence. The astronomically related relief decorations on this temple add to its distinction from surrounding structures. Here we see serpents swallowing the sun disk, an obvious allusion to eclipses. Hieroglyphic representations of the binding of the years are also depicted on the frieze. One sculpture shows a pair of adjacent dates tied together by a rope.

Looking back at Fig. 74a, we also see the emergence of that group of cities having their main axes oriented between 15° and 20° east of north. Hereinafter we shall refer to this group as the " 17° family of orientations." Originating in Central Mexico, the family includes, in addition to Teotihuacán, the pyramid of Tenayuca 30 kilometers to the southwest and the Casa de Tepozteco 100 kilometers to the south, both built immediately before the conquest, and Tula, the Toltec capital 70 kilometers to the northwest. The pattern is also clearly visible in Fig. 74c for the Central Mexican sites. Nearly all sites which belong to the 17° family are found to lie within 100 kilometers of Teotihuacán.

Tenayuca, Tepozteco, and Tula, built much later, may have copied the Teotihuacán orientation. Because of precession of the equinoxes (Chapter III), by the time these centers were erected, the Pleiades (or whatever stellar reference might have been used) no longer set along the Teotihuacán east-west axis. Nor did the Pleiades announce the zenith passage of the sun by the tenth century, a time when the great civilizations of Mexico were already declining. The priest-rulers of these new centers probably looked upon Teotihuacán as a holy city in ruins, much as we do today. In reverence of the past, the new kings planned their centers of worship with the same directional axes. The old alignment must have been transferred astronomically by sighting a substitute star which had replaced the Pleiades. Thus, we regard the axes of Tula and the other members of the 17° group as nonfunctional imitations following the tradition established by Teotihuacán architects and astronomers. By the Post-Classic phase of civilization in Mexico, the original purpose of the orientation seems to have been completely lost.

In 1974, geographer Franz Tichy published the results of an aerial survey of the Central Mexican highlands in the region of Puebla and Tlaxcala. He found that postconquest fields, villages, and towns in the area aligned generally east of north. Three distinct families of axial directions are evident in his data: groups near 7° , 17° , and 26° east of north. The existence of similarly oriented pre-Columbian buildings in the Mexican highlands led Tichy to postulate that the later structures

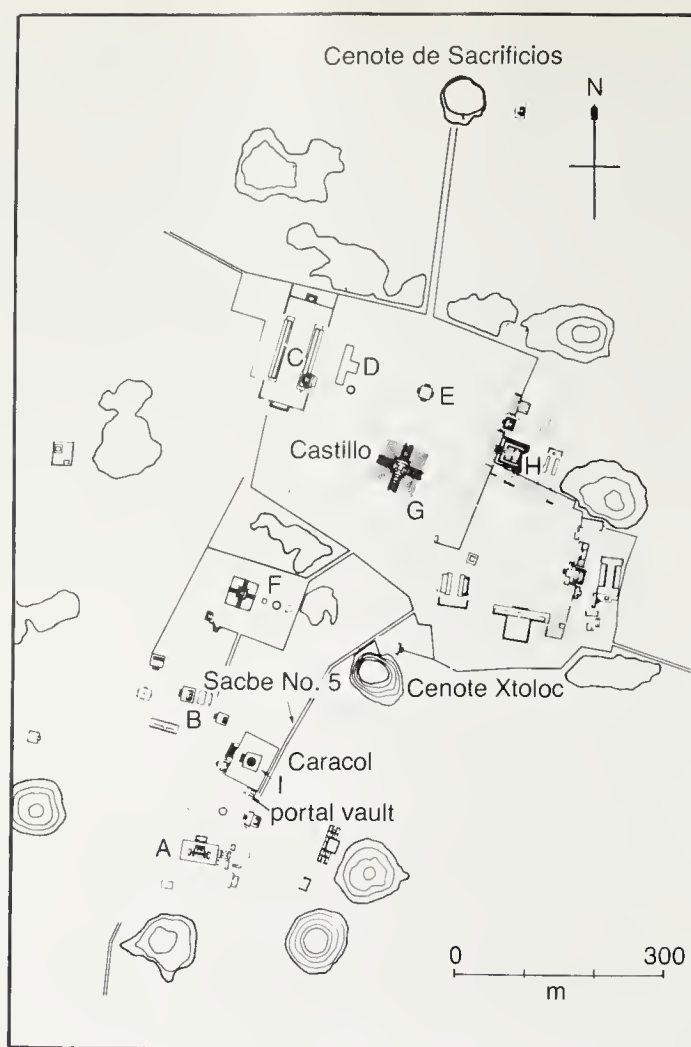


FIG. 75. Plan of Chichén Itzá showing the orientation of principal buildings. (Diagram by H. Hartung)

preserve directions already important in antiquity. Siemens (1979) has found the 17° pattern in raised fields in the tropical lowlands from Veracruz to Belize. Thus, alignment studies can serve as an index of persisting cultural traits.

Often the plans of Maya ceremonial centers seem to exhibit more disarray than those of Central Mexico; however, a closer look at the principal axes of buildings at Chichén Itzá in northern Yucatán reveals that most of them align in three distinctly separate directional categories (the capital letters refer to the buildings in Fig. 75):

(a) 10° – 12° east of north: the Nunnery (A) and the Red House (B), both of the earlier pure Maya style

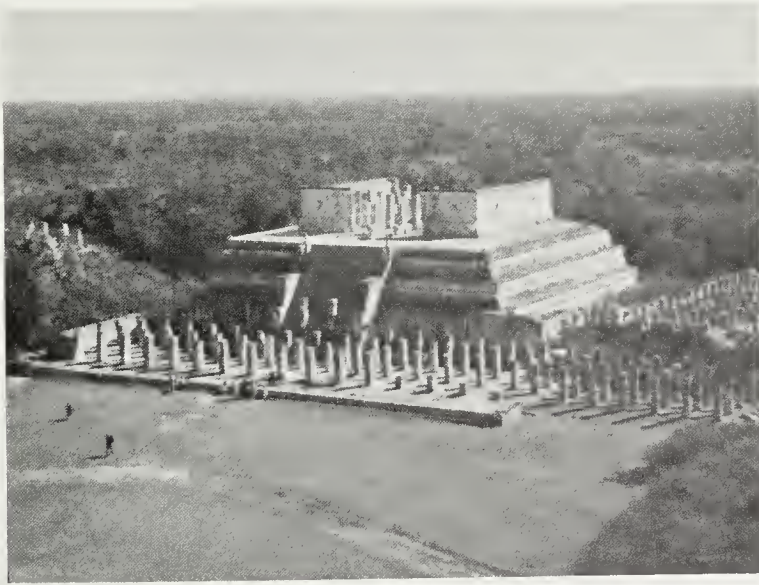
(b) 16° – 18° east of north: the Great Ballcourt (C), Tzompantli (D), Platform of Venus (E), and High Priest's Grave (F), all belonging to the later Toltec period of influence

(c) 21° – 23° east of north: the Castillo (G), Temple of the Warriors (H), and the Upper Platform of the Caracol (I), constructed during the earliest period of Toltec influence.

Does this imply that the basic plans of these cities had been re-structured more than once?



a



b

FIG. 76. Similar buildings of Toltec design possessing the same orientation although they are separated by 1,500 kilometers: (a) Temple B, Tula; (b) Temple of the Warriors, Chichén Itzá.

The buildings of category (b) are members of the 17° family; they also are decidedly of Toltec influence. There is considerable evidence that during the Post-Classic period of Mesoamerican civilization (about the tenth century A.D.), the Toltec people of Tula conquered Chichén Itzá and imposed their artistic and architectural style upon the Maya. Evidently, the conquerors were highly motivated to include their sacred directions for building orientation when they reconstructed the site, an idea which seems altogether surprising in view of the commonly held perception of the Toltecs as uncultured warriors. The buildings of group (c) appear to be aligned with the solstice sunrise and

sunset points, but there is no obvious astronomical match-up for the orientations of group (a). These alignments are positioned within a few degrees of the present magnetic north-south axis in the area. Their perpendiculars coincide with solar horizon positions in late April and late August, not close enough to the solar zenith passage dates to award them any significance.

It is worth pointing out that the ground plan of the city of Tula in Hidalgo in Central Mexico is remarkably similar to portions of that of Chichén Itzá, which is located 1,500 kilometers by land to the east and at nearly the same latitude. The huge Atlantean figures of Temple B at Tula find their miniature counterparts in the Temple of the Warriors of Chichén Itzá (Fig. 76). The two buildings bear a further resemblance to one another: each is fronted with numerous giant columns and adorned with sculpted feathered serpents representing the image of the god Quetzalcóatl, whom the Maya called Kukulcan. Not only are the principal ballcourts at both sites similarly located but they also exhibit identical orientations.

At Copán, Honduras, a classic Maya site, we also find evidence of a reoriented grid plan. Once again three sets of axes are apparent (see Appendix A for details): (a) 6° west of north (the area from the Great Plaza to the Hieroglyphic Stairway); (b) 1° east of north (Court of the Hieroglyphic Stairway); and (c) 5° – 9° east of north (Eastern and Western Courts) (Fig. 77). Unfortunately, we know relatively little about the difference in time between the building periods among these areas.

A 7-kilometer-long base line (d) between Stela 12 on the east side of the Copán Valley and Stela 10 on the west is directed $9^\circ 00'$ north of west. It passes over the archaeological site at the extreme southern end of the West Court where the buildings are oriented in approximately the same direction (Figs. 77 and 78 illustrate). The implied association between building orientations and a long-distance base line parallels the case at Teotihuacán. In this case the stelae replace cross petroglyphs as markers to indicate an important astronomical direction. In the 1920s archaeologist Sylvanus Morley demonstrated that, as viewed from Stela 12, the sun sets over Stela 10 on April 12 and September 1. He connected the first event with initiation of the milpa agriculture, which is still practiced in the area. The setting of the sun along the Stela 12–10 base line officially announced the start of the rainy season in the annual calendar, an event which must be immediately preceded by the practice of the milpa agricultural system—the clearing and burning of the bush. While deeply engaged in his study of Copán inscriptions, Morley, nevertheless, took the time to record in his field notebook the events taking place at this time of year in modern (1925) Honduras:

It is the general custom in western Honduras at the present time to burn off the fields some time early in April to clear them for planting at the beginning of the rainy season, a month later. It is certain, that after burning had once been started, no sunset observation on Stela 10 would have been possible from Stela 12. Such was the hazy smoke-laden condition of the atmosphere from April 9 to 14 of the present year at Copan, that even with a

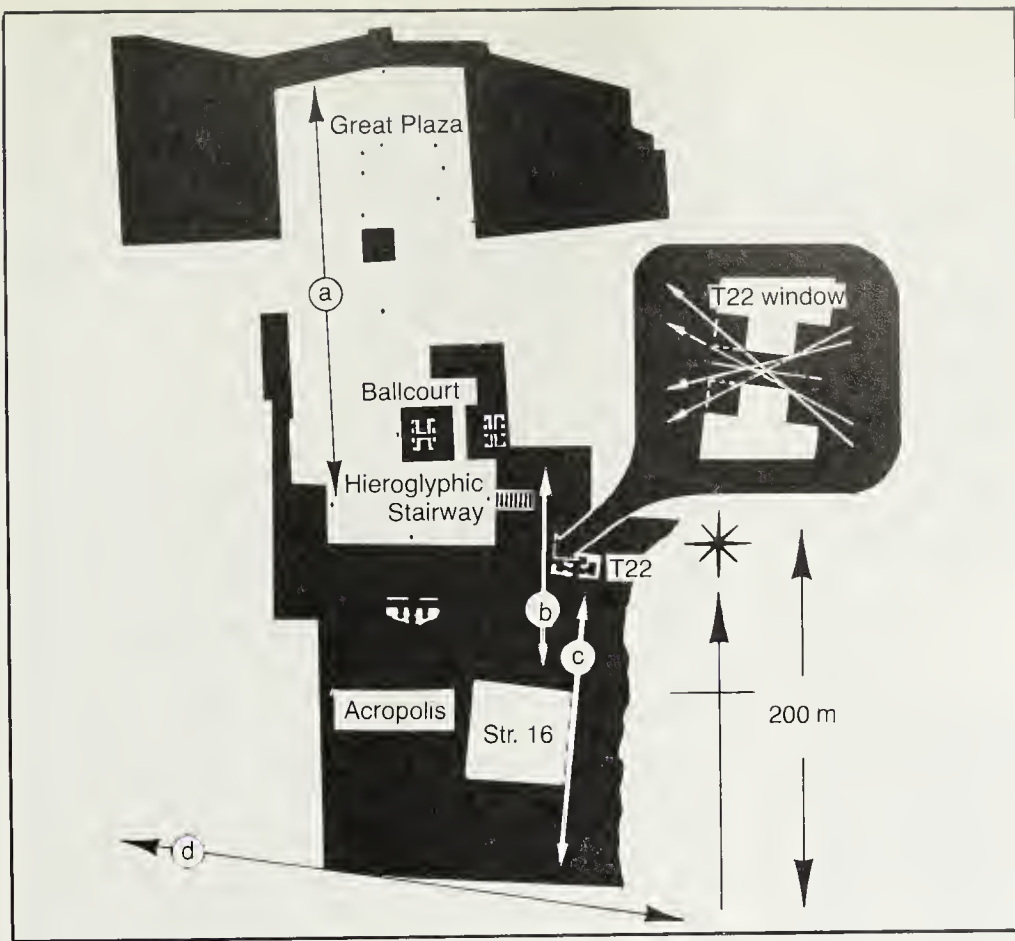
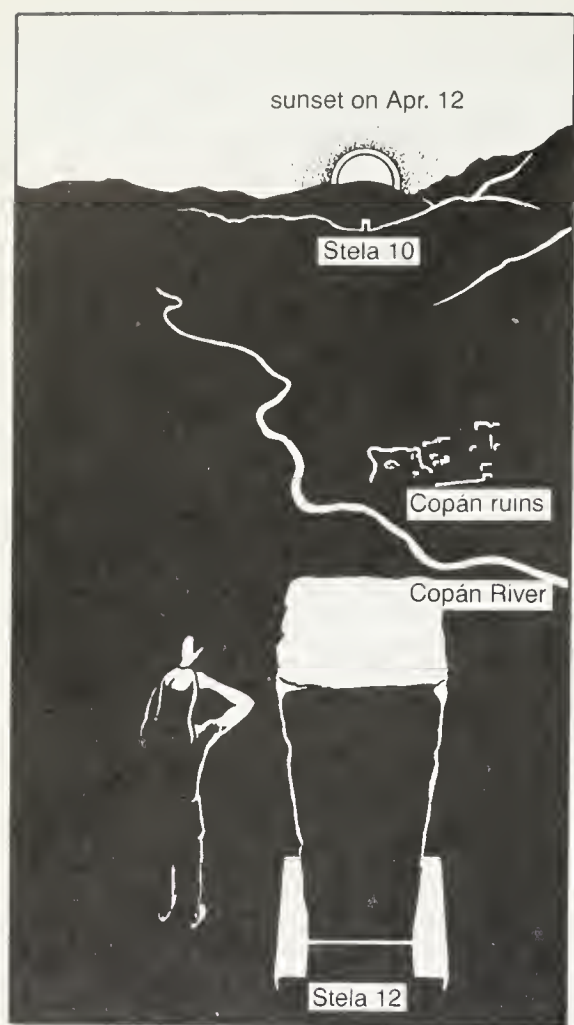


FIG. 77. Plan of Copán showing three principal orientation groups—*a*, *b*, and *c*—and the Stela 12–10 long-distance astronomical base line, *d*, which skirts the base of Structure 16 on the Great Acropolis, Copán's principal structure. The Temple of Venus (Str. 22, enlarged), with its viewing window and viewing lines, is also shown. Dots represent the location of altars and stelae. (Diagram by P. Dunham)

high-powered telescope it was impossible to see Stela 10 from Stela 12 at sunset, and without any instrument of precision it would have been even more hopeless. Indeed, the only way it was possible to secure the azimuth of this line was by erecting behind Stela 10 an enormous pile of fat-pine faggots, 16 feet long and 10 feet high, and setting fire to it at night. This caused such an illuminated field behind Stela 10 that, even in spite of the heavy pall of smoke overhanging the valley, it was possible to see the monument outlined against this illumination and to secure the azimuth of the line. (P. 281)

Charles Wisdom (1940, chap. 14), an anthropologist who studied the Chorti Maya people of nearby Guatemala, notes a careful scheduling of events transpiring at this stage of the agricultural cycle. By the beginning of April all the fields have been cleared of wild vegetation, which is placed in the sun to dry out. By the middle of the month these piles are fired and the ashes employed as fertilizer for the coming crop. The inhabitants prepare for the annual rain-making ceremony and fes-



a



b

FIG. 78. The astronomical base line between Stelae 12 and 10: (a) Large-scale view of the alignment on a plan of the Copán valley; the edge of a large complex at the ruins lies close to the base line and possesses the same alignment to within 3° (diagram by P. Dunham). (b) Looking west from the inscribed Stela 12 toward Stela 10 (arrow); the Copán ruins lie in the valley in between.

tival, which is held on April 25, continuing for eight days until May 2 (20 days after sunset behind Stela 10). The last day coincides in this territory with the passage of the sun across the zenith, an event which may also have figured in the scheduling. Planting begins officially on May 4; on or about May 11 the families hold ceremonies in their milpas (cornfields) to the wind gods, the purpose of which is to ask the latter to bring rain-bearing wind and to blow gently over the milpas so as not to destroy the young plants.

Whether by coincidence or design, sunsets along the Stela 12–10 base line occur approximately midway in time (though not in direction along the horizon) between equinox and Copán solar zenith passage (Merrill, 1945). The April event occurs 21 days after vernal equinox and 19 days before first zenith passage, while the September event takes place 19 days after second zenith passage and 21 days before autumnal equinox. The time diagram in Fig. 79 illustrates the resulting division

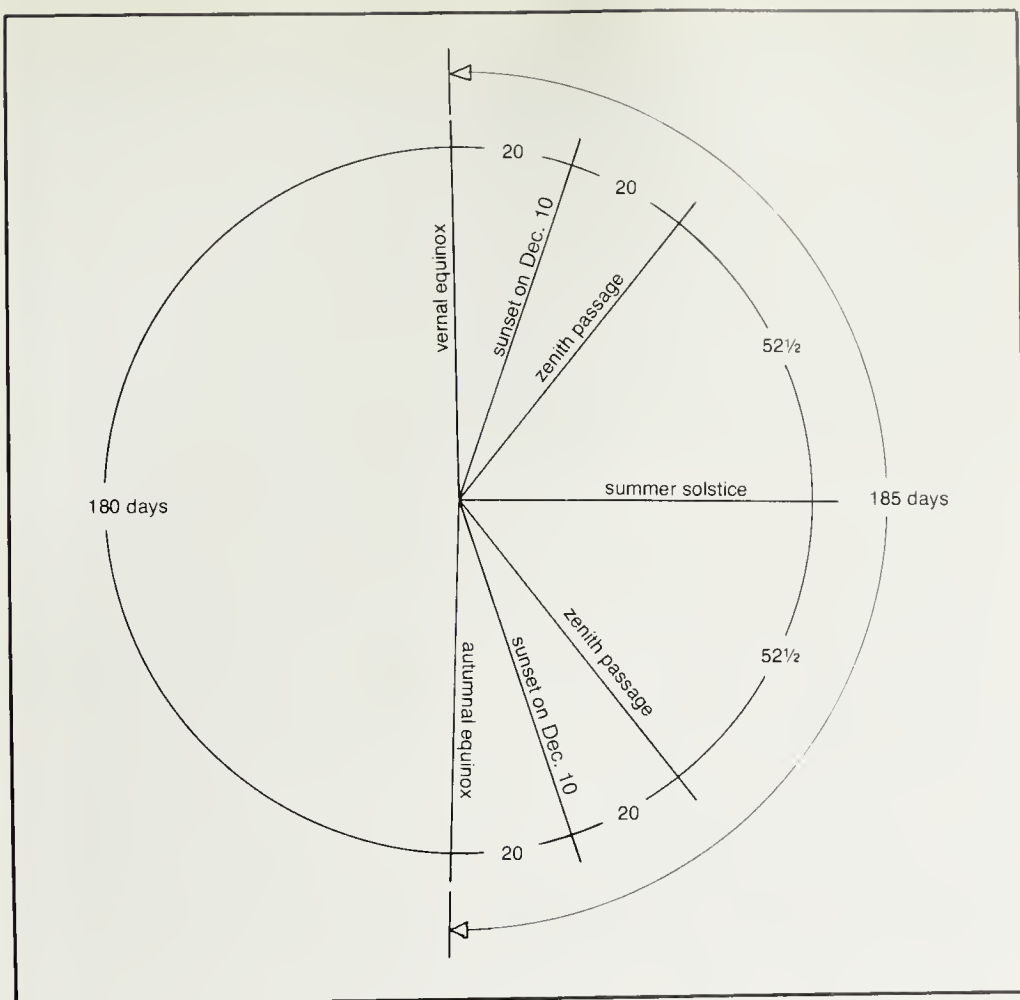


FIG. 79. Copán time diagram showing hypothetical segmentation of the year into uinals based upon sunsets observed along the Stela 12-10 base line on the days of equinox, solstice, and solar zenith passage. Was Copán deliberately situated and oriented to reflect Maya calendric principles? (Diagram by H. Hartung)

of the Copán tropical year into convenient 20-day blocks. Note the inequality in the intervals between autumnal and vernal equinox (180 days) and between vernal and autumnal equinox (185 days), which we discussed in Chapter III. These intervals become surprisingly consonant with the tropical year if we utilize the Stela 12-10 observational base line in our hypothetical calendar. Thus, beginning the year with the second solar zenith passage, we have the following intervals:

Second zenith passage to sunset on 12-10 base line	1 uinal
Sunset on 12-10 base line to autumnal equinox	1 uinal
Autumnal equinox to vernal equinox	9 uinal
Vernal equinox to sunset on 12-10 base line	1 uinal
Sunset on 12-10 base line on first zenith passage	1 uinal
First zenith passage to second zenith passage	5 uinal + 5 kin
Total	365 kin = 1 vague year

The Maya once again unified time and space in the delineation of their vague year at Copán.

In his work on orientations, Tichy has proposed the intriguing idea that Mesoamerican angular measurement may have been "quantized," with certain azimuths occurring more frequently than others according to the special times of the year when the sun rose or set in a particular direction. He finds multiples of a 9° interval in azimuth to be significant. In a thesis on the directions of Maya roads, M. Romanov (1973) has measured the orientation of many of the elevated straight roadways (*sacbeob*) connecting Maya ruins in northern Yucatán. He finds their orientations to crowd around the cardinal points and multiples of 18° therefrom. This is a logical quantum to anticipate for Maya angular measurement since it represents one-twentieth of a circle.

If Stelae 10 and 12 functioned to mark a specific point in the calendar, then might the calendric inscriptions carved upon them provide relevant information? Stylistically, Copán's outlying stelae differ from the huge carved monoliths situated in the Great Plaza. While the latter are mostly figural reliefs, possibly representing a succession of priest-rulers, the hillside monuments contain only dates and hieroglyphic expressions carved in low relief. As we can see from Fig. 78*b* the date on Stela 12 is badly eroded, but a readable Initial Series date appears on Stela 10, the western monument. It is 9.10.19.13.0 3 Ahau 8 Yaxkin. Using the method developed in Appendix B of Chapter IV, we find that this Long Count date converts to the Christian date A.D. July 3, 652 (GMT).⁹ According to modern astronomical calculations, the age of the moon was twenty-two days (23 according to the stela) and it had been partially eclipsed six days earlier. The stela, therefore, gives the first Ahau date following a lunar eclipse, which may have been of some significance in erecting the marker. Curiously enough, if we interpret the date according to the Spinden correlation, we also find something significant. The Stela 10 date converts to A.D. September 6, 392, a time not very far removed from one of the two sunset dates along the base line, September 1 (though the lunar information becomes less accurate). Spinden proposed that the line of sunset originally established occurred on September 6 (and the reciprocal date, April 5). He contends that later the base line was shifted to coincide with the sunset dates given by the present relative placement of the stelae. Dates on Altar U found in the present village of Copán, the site of an earlier settlement adjacent to the main ruins, seem to corroborate his hypothesis. Extrapolating from Calendar Round dates on Altar U, Spinden derives Long Count dates equivalent to A.D. April 9, 480; A.D. September 6, 480; A.D. April 9, 481; and A.D. September 2, 502.

Of further interest in connection with the Copán base line is the Temple of Venus (T22 on the map of Fig. 77), so called because its sculpted doorway is adorned with Venus symbols like those in the Dresden Codex. Excavating on the western side of the building in the 1930s, archaeologist Aubrey Trik (1939) found a single narrow recessed window, the only one appearing at Copán. Facing the western horizon, the shaft bears a distinct resemblance to windows in the Caracol of Chichén Itzá (to be discussed later in this chapter). The axis of the window and its diagonals have been carefully measured with the transit,

and possible astronomical events have been sought for each spatial direction of significance.

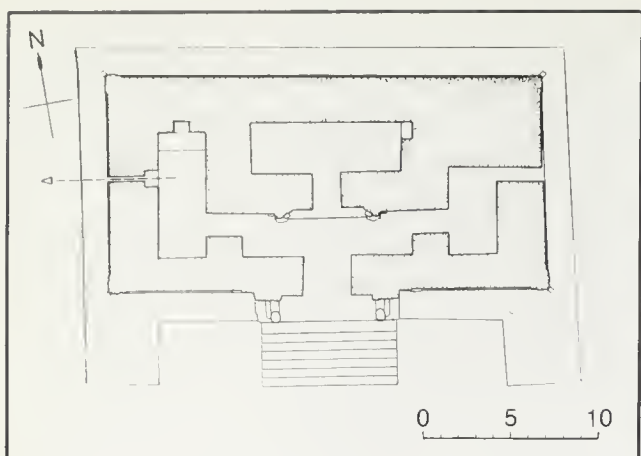
The most significant result of this inquiry was the discovery that the mid-line of the window faces the sunset position on precisely the same dates determined for the Stela 12–10 base line. The absolute difference in the azimuth of the 12–10 base line and that of the axis of the window (amounting to about one solar diameter) can be accounted for by the difference in elevation of the western horizon from the two observation points ($1\frac{1}{2}^\circ$ in the former and $2\frac{3}{4}^\circ$ in the latter). A plan of the Temple of Venus, a photo of the window, and a sketch of the western horizon as viewed from it are shown in Fig. 80. The heavy growth of vegetation along the line of sight through the window prevents a direct view today, but the panorama from the top of the great Hieroglyphic Stairway about 100 meters north of Temple 22 provides a good approximation.

All the evidence points to a connection between Copán acropolis architecture and the Stela 12–10 base line straddling the site. The line itself passes over the southern edge of Structure 16, the largest building at the site, which is oriented to within 3° of the base line according to our transit measurements. The window may have been intended to provide the priests of the temple with a simultaneous sighting of the sunset at the start of the agricultural year while other ritual ceremonies were being conducted at the base of Stela 12 on the slope of the hill to the east. The triad design of shell, flame, and crossbands which adorns the Temple of Venus has been thought to represent the act of fire making. Art historian George Kubler has suggested that the temple may have been used to store the ritual paraphernalia used for the yearly burning of the cornfields (see the discussion in Robicsek, 1972, p. 100).

Michael Closs, a mathematician at the University of Ottawa, offers an alternate explanation for the direction of the window. Since Temple 22 is adorned with Venus symbols, he searched for events involving that planet which could be viewed through the window in Maya classic times. Using a computer program developed by me to follow the motion of Venus in the Copán sky, Closs discovered that the last day of appearance of Venus in the window in successive cycles correlated seasonally with the dates of Venus extrema along the horizon. When one event occurred about April 9, the other took place about May 9. From iconographic and ethnohistoric evidence, Closs et al. (in press) connect Venus with the coming of the rains and suggest that observations taken through the window could have been utilized in a warning system attaching Venus observations to the initiation of the rainy season.

Finally, according to Kelley (private communication), one of the dates associated with the temple is 9.17.0.0.0 13 Ahau 13 Cumku. He argues that it is an eclipse in the Dresden table as well as an inferior conjunction of Venus in the Spinden correlation.

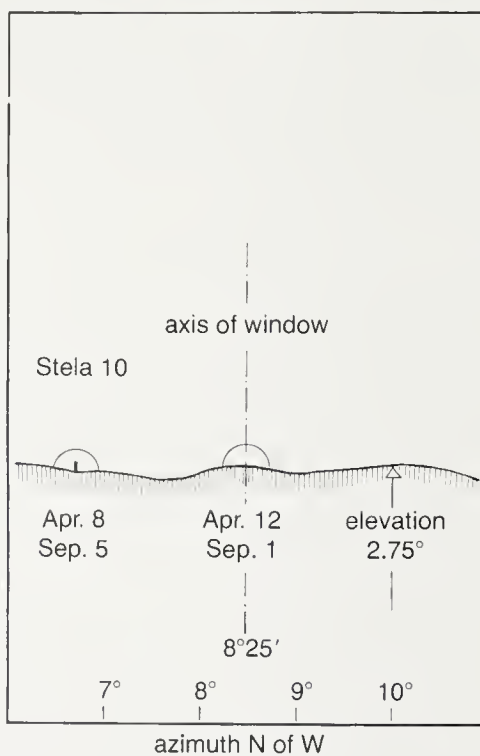
One of the most convincing examples of an astronomically oriented city plan (also east of north) emerges late in the history of Mesoamerica. Tenochtitlán, the Aztec capital, was built by a civilization which can hardly be said to have possessed the astronomical knowledge accorded the Maya. Nevertheless, their capital is of great interest



a



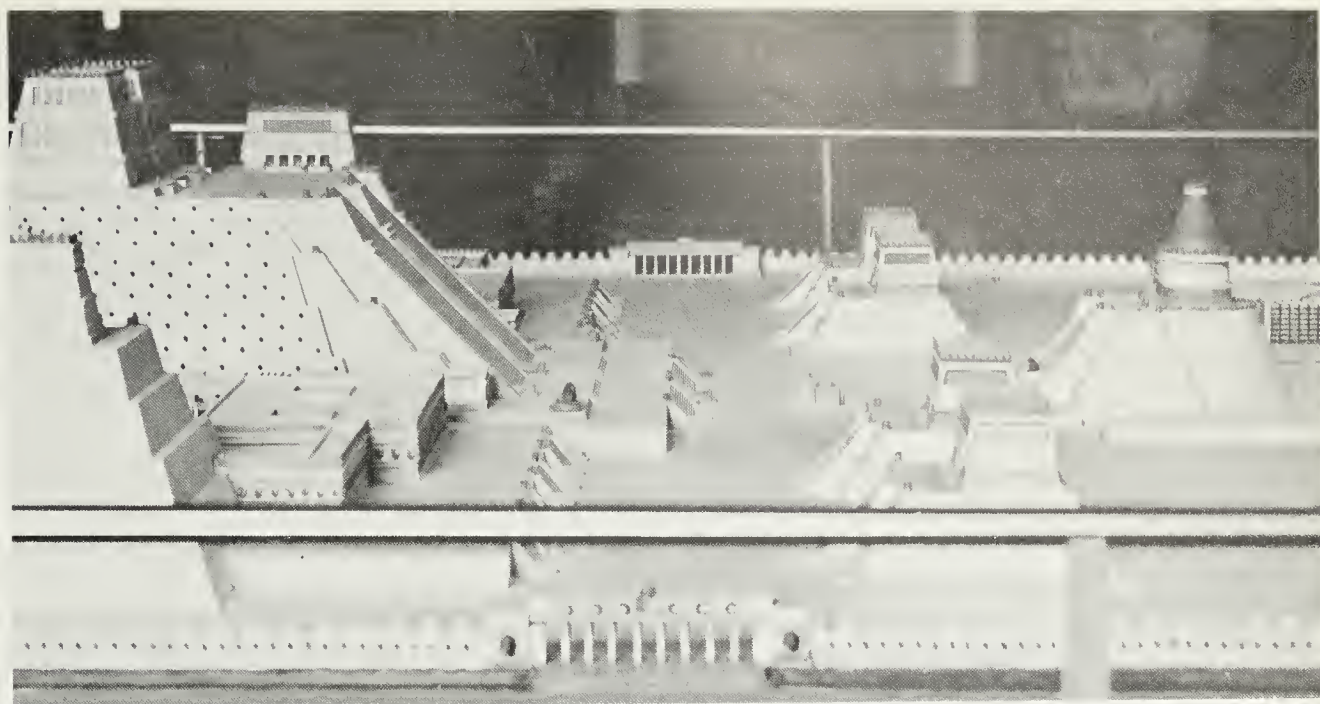
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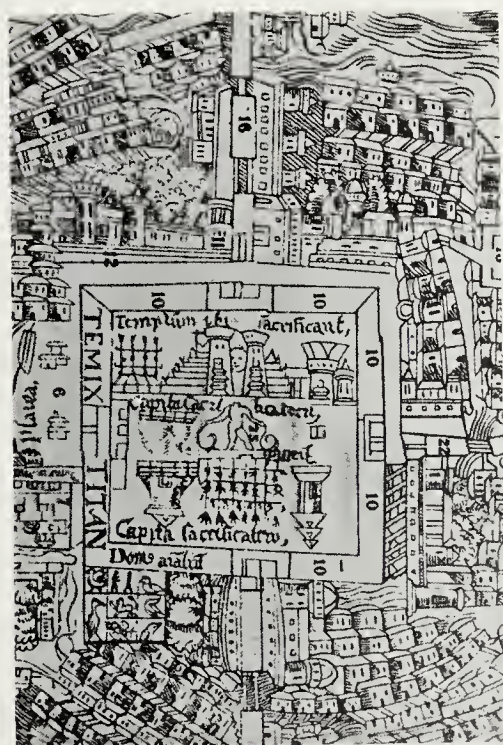
c

FIG. 80. Temple 22—the Temple of Venus—at Copán: (a) plan of Temple 22 showing narrow window facing western horizon (diagram by H. Hartung after Trik, 1939, p. 91); (b) the window of Temple 22; (c) view of the western horizon through the window (diagram by H. Hartung).

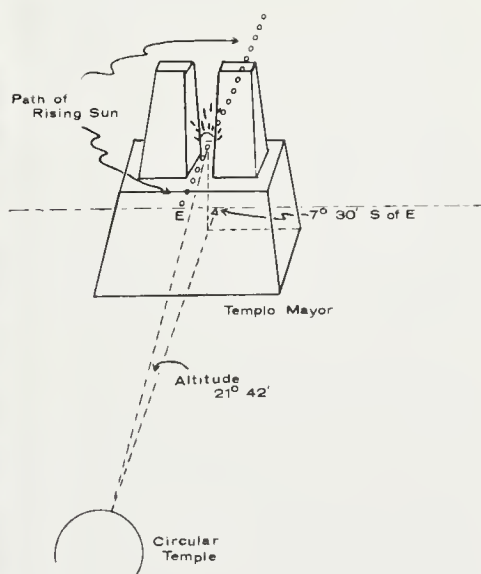
to us, for here we find specific evidence in the early postconquest literature alluding to an astronomical motive underlying the orientation of its most important building, the Templo Mayor (Fig. 81a). Writing shortly after the conquest, the Spanish priest Toribio Motolinía tells us that the festival celebrating the Aztec month of Tlacaxipeualiztli “took place when the sun stood in the middle of the Temple of Huitzilopochtli, which was at the equinox, and because it was a little out of the straight, Moctezuma wished to pull it down and set it right” (Maudslay, 1913, p. 175). Evidently the priest and worshippers faced to



a



b



c

FIG. 81. Astronomical orientation of the Templo Mayor of Tenochtitlán: (a) Templo Mayor and the round Temple of Quetzalcóatl (in a model in the Museo Nacional Antropología e Historia, Mexico City, photograph by H. Hartung); (b) portion of an early map of Tenochtitlán (García, 1910 3:26–27, © The Hakluyt Society, London 1910); (c) orientational diagram showing the path of the rising sun at the equinox.

the east to view the sunrise in the gap between the two oratories atop the great pyramid. British amateur archaeologist Alfred P. Maudslay (1913) found support for this interpretation in a 1524 map of the Aztec capital, attributed to Cortez, which shows a face representing the sun flanked by the twin temples on the top of the Templo Mayor (Fig. 81b).

One might expect from Motolinía's remarks about the equinox that modern measurements of the remains of this structure would find the axis of the Templo Mayor aligned exactly east-west. On the contrary, our measurements on the southwest corner, the only portion of the building extant until the recent revival of interest by the Mexican government, and subsequent excavations, show that the building's axis was directed $7^{\circ}30'$ south of east. But the apparent conflict between historical and archaeological evidence is resolved by a careful consideration of the crucial equinox observation.

The small circular Temple of Quetzalcóatl (*right*, Fig. 81a; *foreground*, Fig. 81c), west of the Templo Mayor along its major axis extended, makes it a suitable spot from which to view the notch between the twin temples crowning the pyramid. The physical location of the Temple of Quetzalcóatl also seems to have been important. It provided an excellent vantage point for witnessing the rising sun taking place there. High on the terrace above, the victim, stretched out on his back over a carved stone and held fast by four assistants, could be seen awaiting sacrifice to the Aztec sun god. This took place when the High Priest plunged a flint knife into the victim's chest and tore out the beating heart, offering it to the sun. This little building, though its location cannot be placed precisely through archaeological methods, also must have been an important structure in connection with timekeeping,¹⁰ for Fray Diego Durán (1971), also writing shortly after the conquest, tells us that at sunrise and sunset of each day a priest on the upper platform of the temple beat a large drum which could be heard throughout the city and which was used as the official signal to start and terminate all business and work of the day.

The observer situated on the axis of the Templo Mayor close to ground level could look over the terrace between the twin towers to see the sun rise between oratories precisely at the equinox. The skew of $7\frac{1}{2}^{\circ}$ east of north may have been necessary because the sun would rise on a slanted path to an altitude of about 20° above the astronomical horizon before it could be seen in the notch from near ground level (Fig. 81c illustrates this curious geometry). This means that the twin temples must have been about 50 meters above the ground in order to effectively frame the elevated sun for a ground-level observer about 150 meters away and on axis. Apparently, the entire ceremonial center was skewed to the east to accommodate the symbolism of the equinox sunrise event.

The consistency of historical and archaeological evidence in the case of the Templo Mayor depends upon the credibility of estimates of its height. By relying on postconquest accounts (including Motolinía's) of the *dimensions* of the temple, architect Ignacio Marquina (1960) has judged the height of the platform on which the oratories stood to have been about 42 meters above ground level. The order-of-magnitude

agreement between Marquina's height estimate and estimates based on archaeological evidence suggests that Motolinía's statements concerning the function of the skewed Templo Mayor are consistent with his statements about its dimensions. It will be interesting to restudy the orientation question in light of the recent excavations of the temple conducted by the Mexican government which have disclosed earlier structures lying beneath the exposed surface.

The Tenochtitlán study (Aveni and Gibbs, 1976) suggests that the vertical dimension should not be overlooked in any study of building orientation. By varying the height of the observer relative to the foreground, whether it be a building or a portion of the horizon, it may be possible to account for many of the orientations skewed 0° to 10° eastward from the cardinal points by sunrise observations at the equinox. Alignments with a larger skew could be explained by a sunrise or sunset observation on one of the significant agricultural, civic, or religious dates of the year, for example the date of passage of the sun across the observer's zenith. Where we see the most extreme deviations from the cardinal directions, for example, group (c) at Chichén Itzá and the Pyramid of Cholula, an observation of the sun at the solstice seems to have been the underlying motive.

ANCIENT MESOAMERICAN OBSERVATORIES

Having discussed certain peculiarities in the large-scale planning of Mesoamerican ceremonial centers, we turn our attention to an examination of individual buildings possessing peculiar shape and/or orientation relative to other buildings at a given archaeological site. Such structures immediately arouse our suspicion. Could a wall or a doorway have been deliberately shifted out of place in order to serve as a sighting post to register a special celestial event? One of the most peculiarly shaped buildings in Mesoamerica is Building J at Monte Albán, a Zapotec ceremonial center constructed on an artificially leveled mountaintop overlooking the valley of Oaxaca, 500 kilometers southeast of Mexico City. This unusual edifice shows up clearly in an aerial photograph of the site as well as in the view from ground level (Fig. 82). While all the buildings within and around the 1-kilometer-long plaza area are oriented 4° to 8° east of north, Building J appears to be conspicuously out of line—by about 45° , relative to the rest of the buildings. Alfonso Caso (1935), the Mexican archaeologist who excavated Monte Albán in the 1930s, immediately noticed the peculiar situation of the building, stating that, while most of the other buildings at the site had their axes cardinally oriented (actually they are aligned a few degrees clockwise from true north as the data in Appendix A suggest), Building J had its stairway facing to the northeast. He also noted that its plan did not conform to the quadrangular shape of the other structures. The form of Building J resembles that of "home plate" on a baseball diamond. The plan of the building reveals that no two sides or angles are equal. A prominent open doorway, visible in both views shown in Fig. 82, adorns the top of the structure, which was built over an earlier edi-



a



b

FIG. 82. Monte Albán: (a) the odd shape and orientation of Building J are revealed in this aerial view (courtesy of Compania Mexicana Aerofoto, S.A.); (b) ground-level view from the southwest; Building J lies in the foreground. Note the prominent open doorway at the top; it faces Building P and the rising point of Capella (arrow).

fice with slightly different orientation. In fact, archaeologists associate at least three building periods with Building J, the first commencing before 250 B.C.

Caso suggested that a horizontal tunnel cut through the rear (SW)



FIG. 83. How the western sky would have appeared from Building J at the time it was constructed.

portion of the building could have been used for making astronomical observations; thus evolved the popular reference to the structure as the "observatory of Monte Albán." Actually, because of its zig-zag shape, Caso's chamber does not give clear access to the sky, much less to any part of the horizon. In Fig. 82a the observer's attention is drawn immediately to the point of the arrow at the southwest corner of the building. Examined from above, the structure directs our view toward a distant point on the southwestern horizon. What was happening at that particular azimuth in 250 B.C. when the Zapotecs built their city? The answer can be found in the artificial environment of a planetarium. Adjusting the sky to the north latitude $17^{\circ}03'$ and time 250 B.C., we obtain the view of the western sky shown in Fig. 83. It is exactly as the worshippers at Monte Albán would have seen it. The bright stars of the Southern Cross (numbered 3, 4, 5) and the fainter unlabeled star below 5 followed by the two first-magnitude stars Alpha and Beta of Centauri (1, 2) all drop behind the western horizon in the approximate direction in which Building J points (black arrow in diagram), as we can see from the artificial star trails in the photograph. Now, the five labeled stars are among the twenty-five brightest in the sky and all set within 3° of the direction of the arrow. Is it a mere coincidence that the Southern Cross, one of the most prominent constellations in the sky, set so close to the arrow point at precisely the correct building epoch? The setting position of the cross has moved 15° southward in the two millennia since the building was constructed. We can never answer the question with certainty since the inhabitants of Monte Albán left that place 1,000 years ago. The ethnographic evidence cited in Chapter II suggests



a



b

FIG. 84. Possible astronomical symbols carved on the walls of Building J: (a) the crossed-sticks symbol (cf. FIG. 5); (b) a possible three-pronged sighting device (cf. FIG. 7).

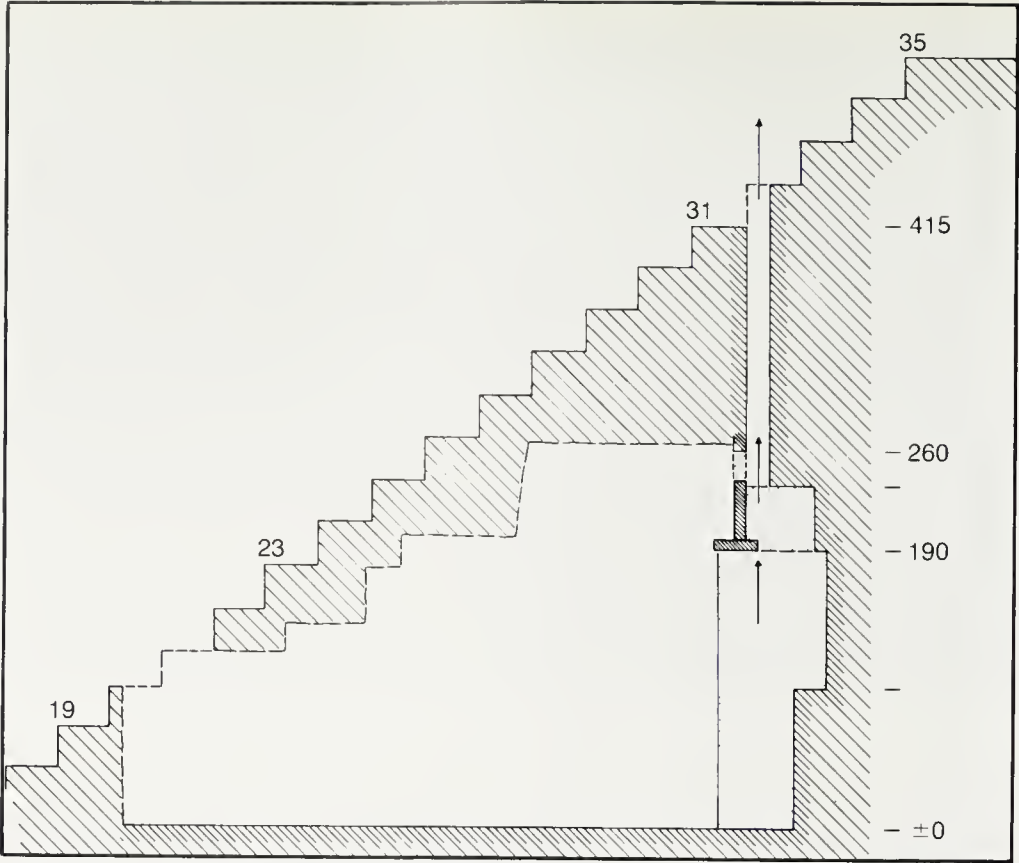
that the Southern Cross was of considerable importance in Mesoamerica. The Aztecs venerated it as a "beautiful bird with a bone piercing its body," Father Diego Durán tells us. "Feasts were regulated by its appearance and disappearance at different times of the year" (1971, pp.

418–419). Its appearance on certain occasions was taken to be a time to pray to the gods for good crops and sound children.

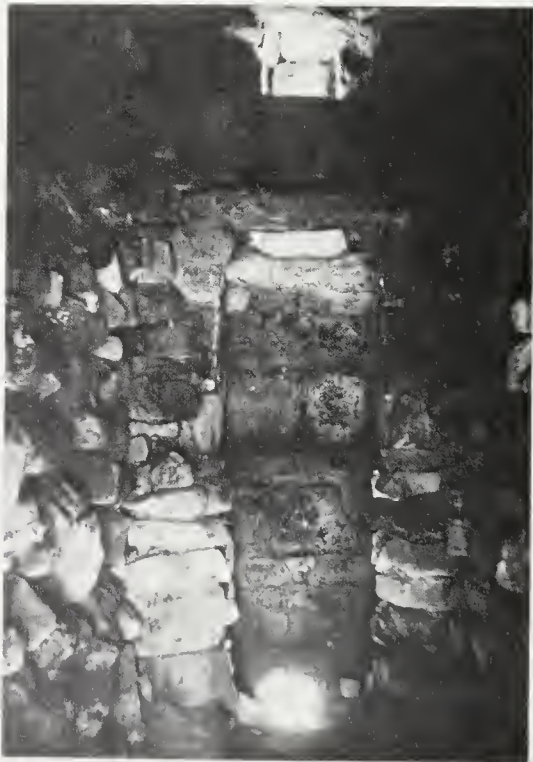
Low-relief carvings on Building J strongly suggest an astronomical use for the building. On its walls the cross-stick symbol is clearly shown adjacent to a low-relief carving of another possible sighting device (Fig. 84). Both are likely representatives of astronomical sighting devices depicted in the codices and discussed in Chapter II. Can they be taken to suggest that the *front* of the building was skewed deliberately to face a particular astronomical event on the northeast horizon? A simple measurement provides evidence on this question. The orientation of a line running northeastward along a perpendicular from the doorway of the building was found to pass over an opening in the stairway of Building P, a large structure located on the eastern side of the open plaza. The opening is visible as a small black dot in the aerial photograph of Fig. 82a (see also Fig. 86). Descending into a dark chamber in the stairway of Building P, one is led back a few meters to a bench beneath a tiny hole passing vertically through the stairway. The hole permits a 2°-wide view of the zenith. In Fig. 85a we illustrate the geometry of the tube in cross-section. The chamber could have functioned as an observatory especially designed to view the Pleiades, which transited the zenith of Monte Albán at this time, or perhaps the image of the sun which would be cast at the base of the hole at high noon on the days of zenith passage in the valley of Oaxaca (May 2 and August 10). The photo in Fig. 85b shows the event actually taking place on August 10, 1976, as the sun still keeps its ancient appointment. In Fig. 85c we illustrate the geometry of another zenith sight tube, one of two built into the cave "Los Amates" at Xochicalco.

Now, the notion of a solar sighting by passage of light through a hole, as opposed to the Old World idea of shadow casting with a gnomon, is not without precedence in the ethnographic record of Native American people. Parsons tells us that the Zuni priest follows a rite of drawing the sun down by observing its light through an aperture in the roof of his hut:

In the roof of the ceremonial room there is a hole through which at noon the sun shines on to a spot on the floor near where the chief now stands. In front of the chief stand his assistants, then the row of the other men present, and then the row of women present. All turn to face the east, singing to call the sun. This is repeated in the antisunwise circuit, before each song each sprinkling meal from the meal basket or pollen received from the chief assistant. All return to their places, except the chief, who makes drawing-in motions from all the directions from the corn mothers, throws pollen up toward the roof hole, and points upward with his stone knife. All sing the song of "pulling down the sun," while the chief makes the motions of drawing something toward himself. Now the sun drops down on the spot of sunlight on the floor. It is a round object, white as cotton, which opens and closes. To this the chief ties the prayer feathers, as all sing. All stand and throw pollen toward the sun object. The chief waves the sun object which shines so brightly you can hardly look at it.

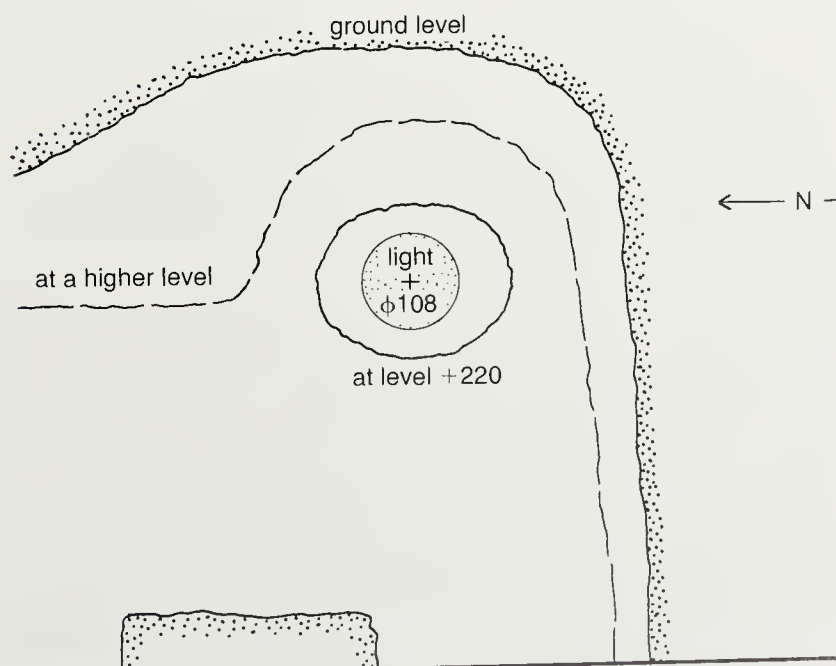
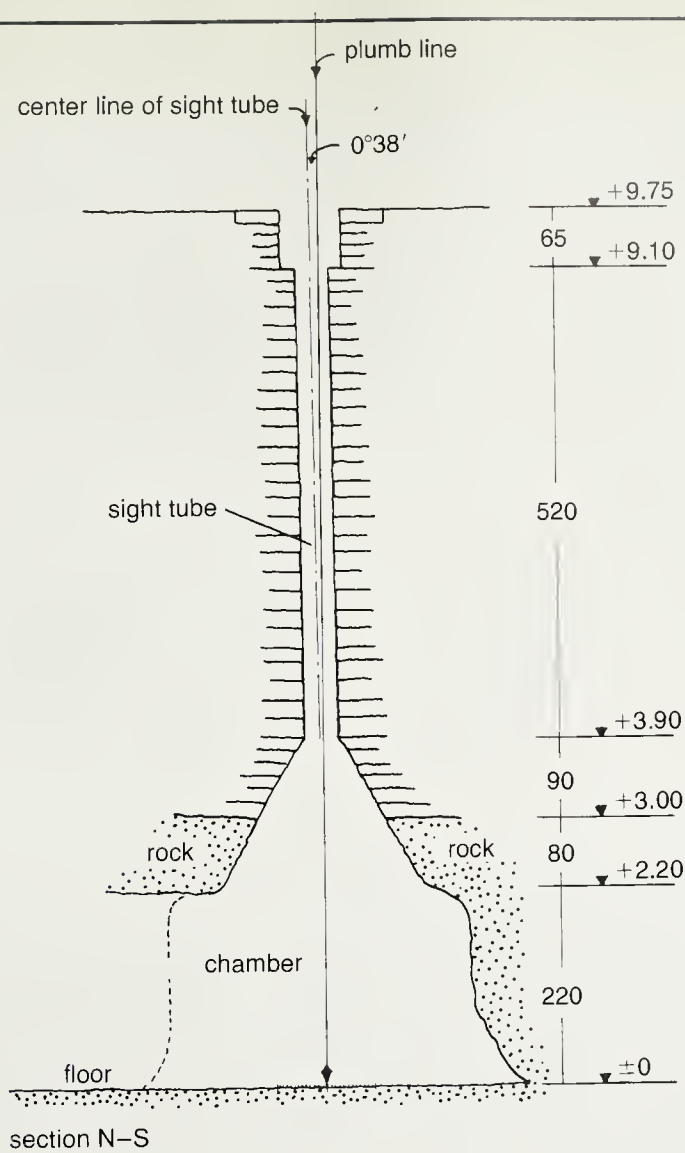


a



b

FIG. 85. (a) Schematic diagram of the zenith sighting tube in Building P (diagram by H. Hartung); (b) the zenith sun still casts its rays down the vertical viewing tube (photograph courtesy of H. Hartung); (c) geometry of a similar tube at Xochicalco (diagram by H. Hartung).



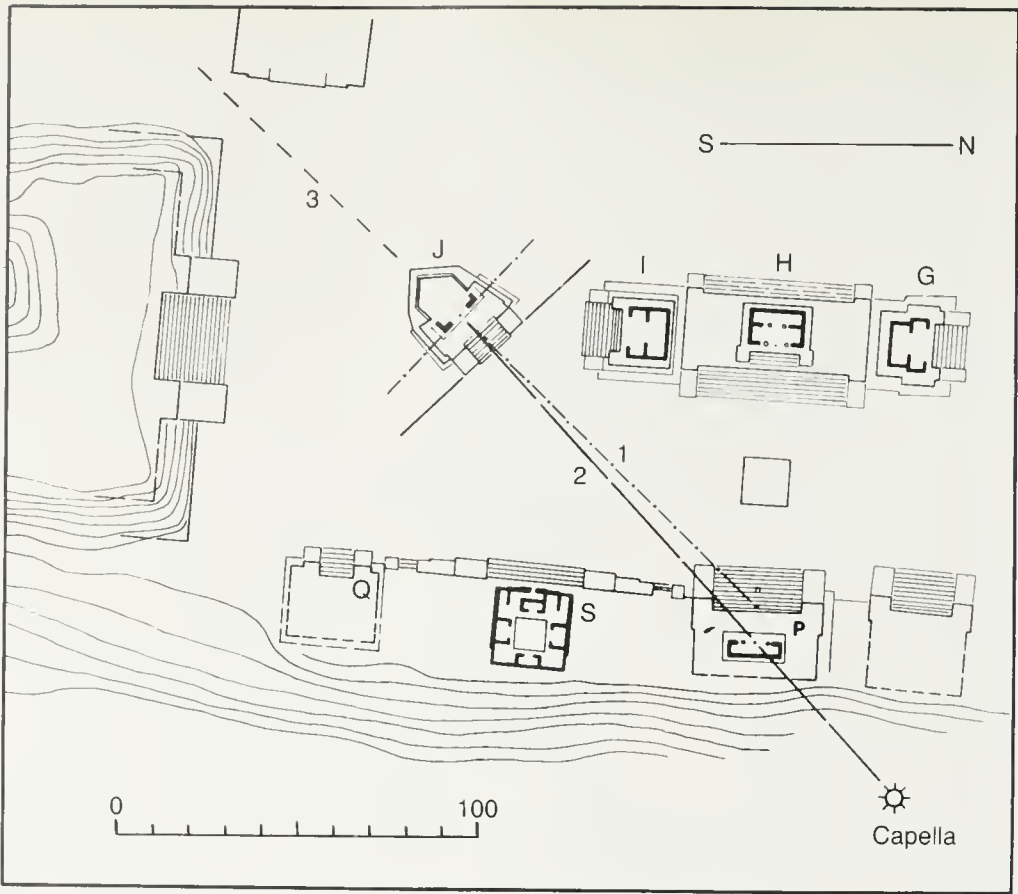


FIG. 86. Plan of Monte Albán showing the astronomical alignments associated with Buildings J and P: (1) perpendicular to doorway of Building J passing to opening in stairway of Building P giving access to observing chamber; (2) perpendicular to stairway of J passing to doorway of P, which points to Capella rising; (3) bisector of arrow shape pointing to five bright stars. (Diagram by H. Hartung)

(The room has been darkened by closing windows.) All breathe on their clasped hands. As the chief waves the sun around his head the sun goes back through the roof hole. This is noontime when for a little while the sun stands still. Elsewhere in the town at this time, knowing the work that is going on (in the ceremonial houses) people withdraw indoors or stay in and ask the sun to help. (1932, p. 292)

Also, holes in the west wall of the ancient adobe temple at Casa Grande, Arizona, have been found to align accurately with the sun at solstices and equinoxes (Evans and Hillman, 1979).

Upon further examination of the geometry of Building J, we find an additional orientational clue. The outer stairway is turned about 4° from the direction of the doorway. It appears that this, too, might have been deliberate. A perpendicular line followed northeastward from the stairway of J passes exactly through the doorway atop Building P, then goes on to strike the horizon at the rising position of Capella, sixth brightest star in the sky. At Monte Albán in 250 B.C., Capella may be singled out from among all the bright stars since it related to the solar

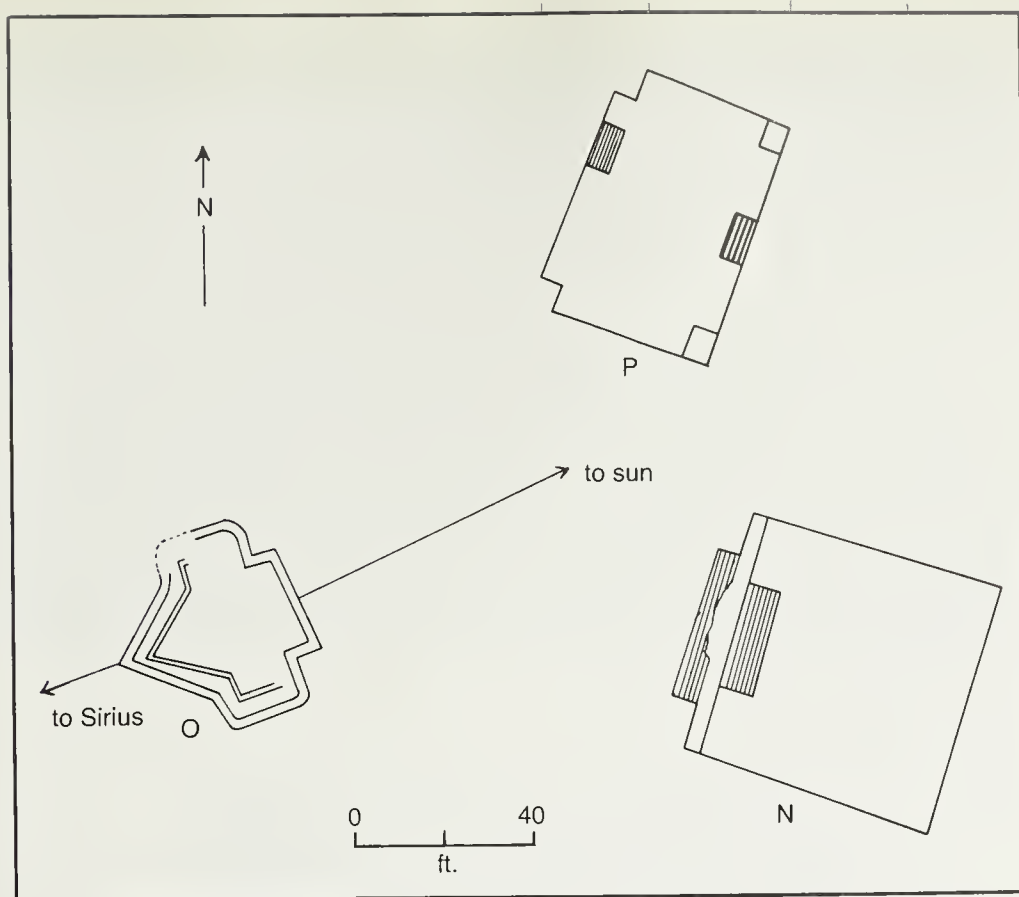


FIG. 87. Structure O, Caballito Blanco; the plan illustrates possible astronomical orientations. (Diagram by H. Hartung)

year in precisely the same way as did the Pleiades at Teotihuacán. We can use Tables 3 and 10 in an approximate fashion to determine that Capella underwent its heliacal rising on the same date as the first solar zenith passage at Monte Albán (about May 2). Fig. 86 illustrates the relationship in the landscape architecture. The pieces of the architectural puzzle now began to fit together harmoniously. The peculiar orientation of the front of the building was both functional and symbolic. The astronomer-priest, having sighted the first annual predawn appearance of the "announcer star" Capella from his sighting post in the doorway of Building J, could foresee the imminent passage of the sun across the zenith. He would then descend into the stairway of Building P to observe it formally. The ritual attending these events could then be celebrated. Evidently, these cosmic occurrences were so important to the Zapotecan priests that they wished to endow their earthly realm with symbols of a permanent heavenly presence. What appears as asymmetric architecture to us was to the astronomer of antiquity a representation of the ordered harmony between earth and cosmos.

Fifty kilometers east of Monte Albán at the top of a small plateau lie the ruins of Caballito Blanco and a building with the same curious wedge shape as Building J. Measurements revealed that Building O, constructed about the same time as J, has approximately the same orientation relative to neighboring structures at Caballito Blanco as does Building J relative to the buildings at Monte Albán, though the abso-

lute orientations of the two buildings differ by 30° . A plan of this minor site, shown in Fig. 87, reveals a few more oddities: the arrow shape is more evident in O, a building of more modest proportion than its impressive counterpart to the west. Astronomical directions of significance also turn up in the analysis of Building O. The perpendicular to the front of the structure terminates on the elevated northeast horizon exactly at the position of the first gleam of sunrise on the summer solstice. The direction of the arrow point also has astronomical importance. It touched the southwest horizon, within $1/4^\circ$ of the setting position of Sirius, the brightest star in the sky. Like Capella, this star appears to have been of particular significance not only because of its brilliance but also, more importantly, because a careful skywatcher could have used the occasions of its heliacal rising and setting to divide the year into the seasons. At Caballito Blanco, Sirius made its heliacal rising close to the first day of summer, and the first day of winter was the last occasion on which it would have been seen rising in the east after sunset. These relationships can be derived approximately from an examination of the heliacal rise-set dates of bright stars in Table 10 (use the columns labeled 500 B.C. and A.D. 0 and interpolate to a point midway between them). If we allow a larger margin of error (4° or 8 sun disks), we can interpret the arrow point of Caballito Blanco as an approximate winter solstice sunset marker.

It is difficult to know whether Building O actually was designed to serve an astronomical purpose (much less which object it was intended to register) or whether it is a nonfunctional imitation of Building J at Monte Albán. In both cases the direction of the pointer indicates a stellar event, while the front of the building seems to be tied to a solar relationship. If we are willing to stretch the margin of error, we might even conceive of the pointed end of structure O as a solstice indicator. In any event, these special astronomical relations that we find imply that its builders once again were attempting to relate their earthly environment to the heavens by incorporating significant and useful astronomical directions into their architecture.

We have no clues to explain the origin of the peculiar arrow form in the plan of the two structures. Aside from these two buildings, no other example of such a shape is found in all of the Mesoamerican architecture.

If Building J is the most peculiar observatory in Mesoamerica, the Caracol tower at Chichén Itzá in Yucatán (Fig. 88a) is surely the most famous. So beguiling are its asymmetries that Sir Eric Thompson, the late dean of Maya archaeologists, was once moved to remark (apparently in half-comic disgust):

Every city sooner or later erects some atrocious building that turns the stomach: London has its Albert Hall; New York, its Grant's Tomb; and Harvard, its Memorial Hall. If one can free oneself from the enchantment which antiquity is likely to induce and contemplate this building in all its horror strictly from an aesthetic point of view, one will find that none of these is quite so hideous as the Caracol of Chichen Itza. It stands like a 2-decker wedding cake on the square carton in which it came.



a



b



c

FIG. 88. The Caracol of Chichén Itzá, one of Yucatán's three round tower observatories: (a) view from the west, (b) stylobate structure, (c) the windows at the top of the Caracol.

Something was pretty clearly wrong with the taste of the architects who built it.¹¹ (1945, p. 10; see Aveni, Gibbs, and Hartung, 1975, for details)

Thompson's frustration with the plan of the tower, which is illustrated in Fig. 89, seems further justified when we look at Oliver Ricketson's description of the unorthodox nature of the architecture he encountered when he excavated the building nearly half a century ago:

The Caracol is a circular tower with four outer doors facing the cardinal points of the compass. Within is a circular corridor from which four more doors, facing midway between the cardinal points, lead into another circular corridor. The inner circular corridor surrounds a masonry core inside which a small spiral staircase¹² leads to the top of the building—. Near the top of the structure is a flat area from which open three rectangular horizontal shafts. The largest of these, No. 1, faces west and until recently was the only one known. Windows 2 and 3 face southwest and south respectively. (1928, p. 219)

To complicate matters, accurate modern measurements (made with the transit, using an astronomical sighting) indicate that all of the implied symmetries in the foregoing passage (windows facing south and east, doorways pointing to the cardinal directions) are really marked asymmetries. Actually, the doorways are skewed 10° to 12° from the cardinal points, and the openings in the inner chamber are not quite halfway between the outer doorways. By observing such asymmetries in Maya architecture, Thompson was led to remark that the Maya seemed to have been incapable of making a true right angle, a statement which does not necessarily follow.

The Caracol's lack of aesthetic appeal has led some investigators to suggest a functional motivation for its design. It has been called the gnomon of a huge sundial as well as a military watch tower, but of all the uses, astronomical observations seem most successful in accounting for the peculiarities of its structure and orientation.

The Lower Platform, the first building unit of the Caracol, was constructed by the Maya about A.D. 800. It is a large rectangular area 52 meters east-west by 67 meters north-south, elevated 6 meters above the flat terrain. Only the large front stairway is visible in Figs 88*a* and 89. It faces $27\frac{1}{2}^\circ$ north of west (Fig. 89, alignment A-1), well out of line with the other buildings at Chichén Itzá. The sunset position at summer solstice lies within 2° of this direction, but an even closer match is provided by the northernmost setting position of the planet Venus. We recall from our extended discussion of the motion of Venus in Chapter III that the planet will arrive at particular horizon extrema every eight years and that the Venus standstills can prove useful in predicting the length of the disappearance interval, which seems to have been the Maya's prime interest associated with that planet.

Above the Lower Platform, imbedded in the stairway of the Upper Platform, we find a niche containing a pair of columns—the so-called stylobate (Figs. 88*b*, 90). This niche is aligned asymmetrically relative

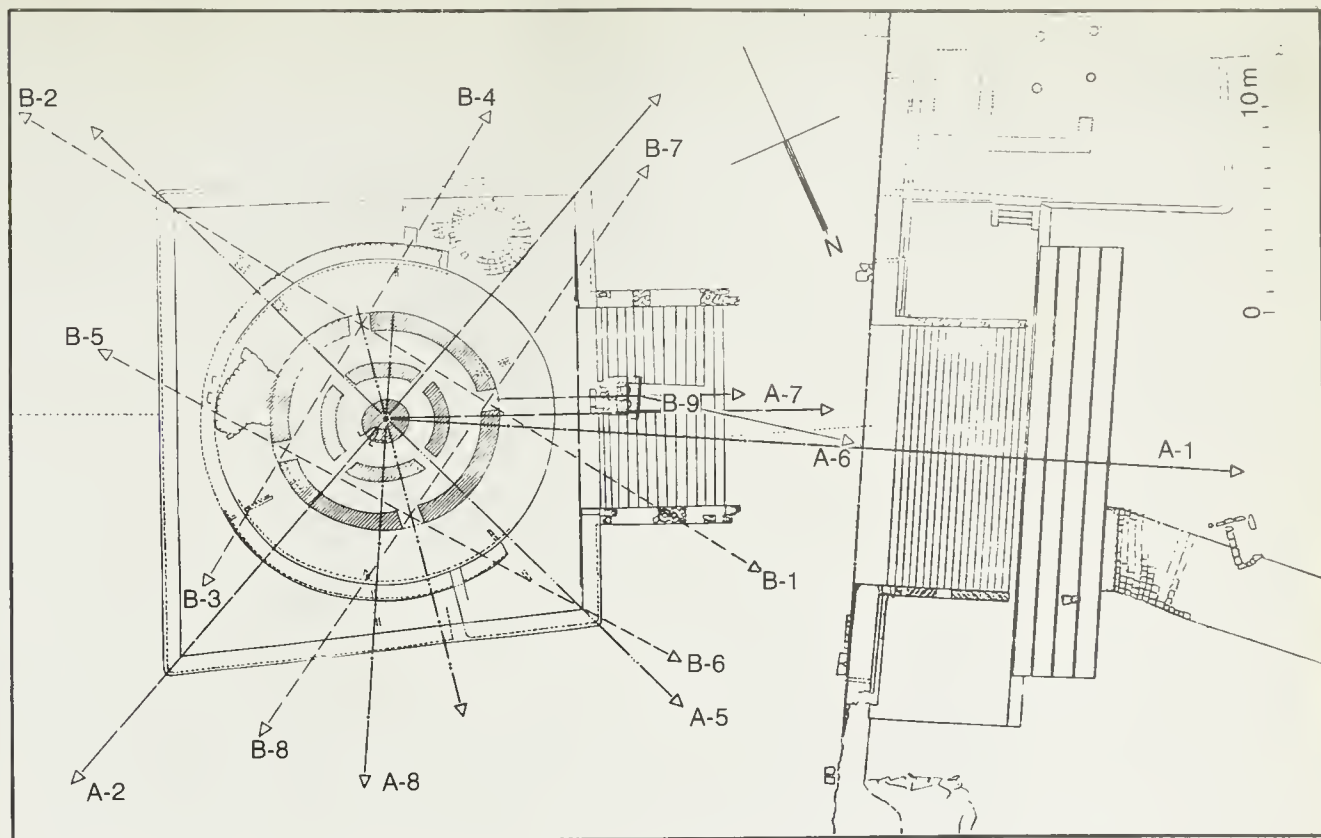


FIG. 89. Plan of the Caracol displaying the most important astronomical orientations: (A-1) the perpendicular to the base of the building matches Venus sets at maximum northerly declination (the same as one of the alignments taken in the windows); (A-7) a perpendicular to the base of the Upper Platform matches sunset on the day of zenith passage; (A-2) the corner-to-corner diagonal points to the summer solstice sunrise. (Aveni, Gibbs, and Hartung, 1975, fig. 5)

to the Upper Platform, pointing once again to the northern Venus extreme. The columns retain flecks of black and red paint. Since these are directional colors in Maya religion, it is possible that the painted stylobate could have served as a monument to Venus in the east as morning and in the west as evening star. *Chac ek*, the common Maya name for morning star means red star or great star.

The color relation is further emphasized in the writings of Caso, which imply a specific association with Quetzalcóatl, the Venus god of Central Mexico: "... the flight of Quetzalcóatl from Tula to the mythical Tlillan Tlapallan, 'the land of the black and the red,' his name, *Ce Acatl*, is but a mythical explanation of the death of the planet, his descent into the West, where the black and the red, night and day, merge, and the prophecy that he will reappear in the East as the morning star, preceding the sun" (1958, p. 25).

What attracted the Maya to worship Venus rather than some other planet? While the record of Venus observations is well documented, there is scarcely a hint that any other planet was given the slightest attention. Admittedly, Venus is the brightest object in the sky, except for the sun and moon, but the reason for the Venus fixation may derive from the Maya fascination with numbers—magic numbers which fit

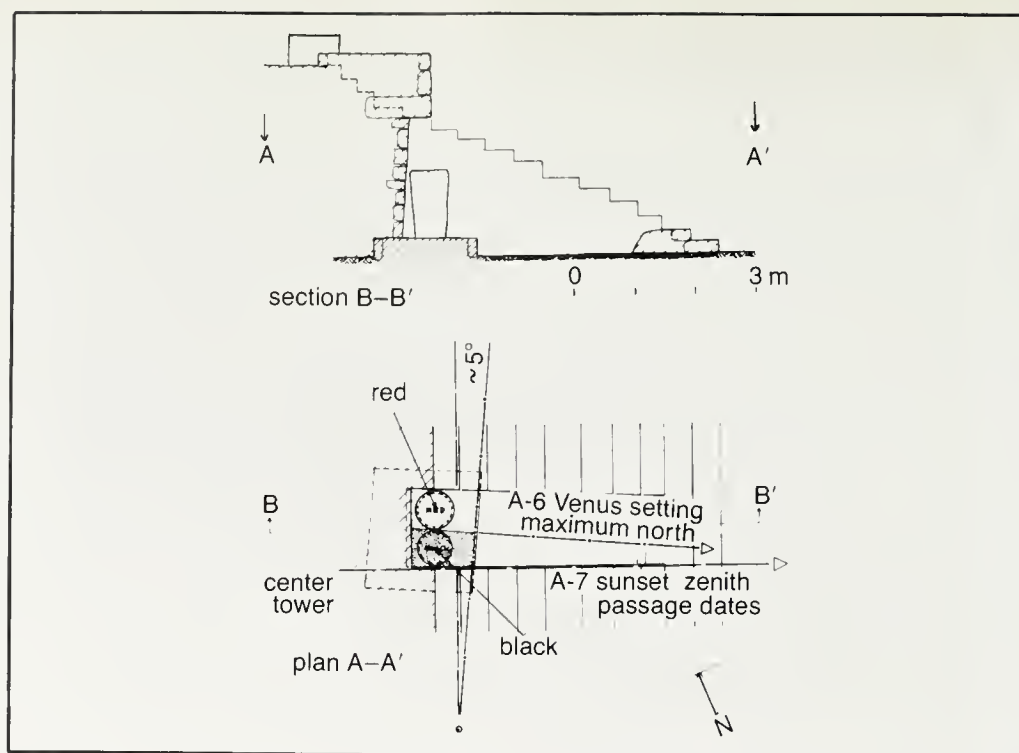


FIG. 90. Plan of the stylobate and platform showing skewed orientation toward Venus. (Aveni, Gibbs, and Hartung, 1975, fig. 4)

together to form cycles, like the 2,920-day periodicity discussed in Chapter IV on calendric cycles.

Venus possesses a special symbolism in connection with Caracol architecture since this luminary represents the celestial manifestation of the man-god Quetzalcóatl-Kukulcan, a deity who in the form of the wind god, Ehecatl, is symbolized by round structures throughout Mesoamerica. He is the one pictured in various evil manifestations in the Venus tables on pages 46–50 of the Dresden Codex, especially when he makes his first appearance in the predawn sky. Recall that these tables give heliacal rise-set dates and ritually significant times of appearance and disappearance of the Venus god in the sky. As we have seen, the Venus tables provide a means of relating ritual site function to observations of the planet at about the time the Caracol was erected. Furthermore, the Venus tables were drawn up not far to the east of Chichén Itzá. Thus, it is very probable that the astronomical observations delineated in the Venus tables in the Dresden Codex were collected by astronomers perched in the observation chamber of this tower and possibly in similar observatories in northern Yucatán. In view of all the evidence, it seems surprising that an intimate connection between Venus and the Caracol was not realized until recently. Perhaps the elusive motion of the planet contributed somewhat to its neglect by modern investigators. The ancient Maya seemed to have mastered the planet's course quite well.

A priest ascending to the top of the Caracol tower would have been able to make two more Venus observations in the "windows" (Fig. 88c). Three horizontal shafts, which emanate from a small rectangular chamber, look out onto the flat southern and western landscapes. The

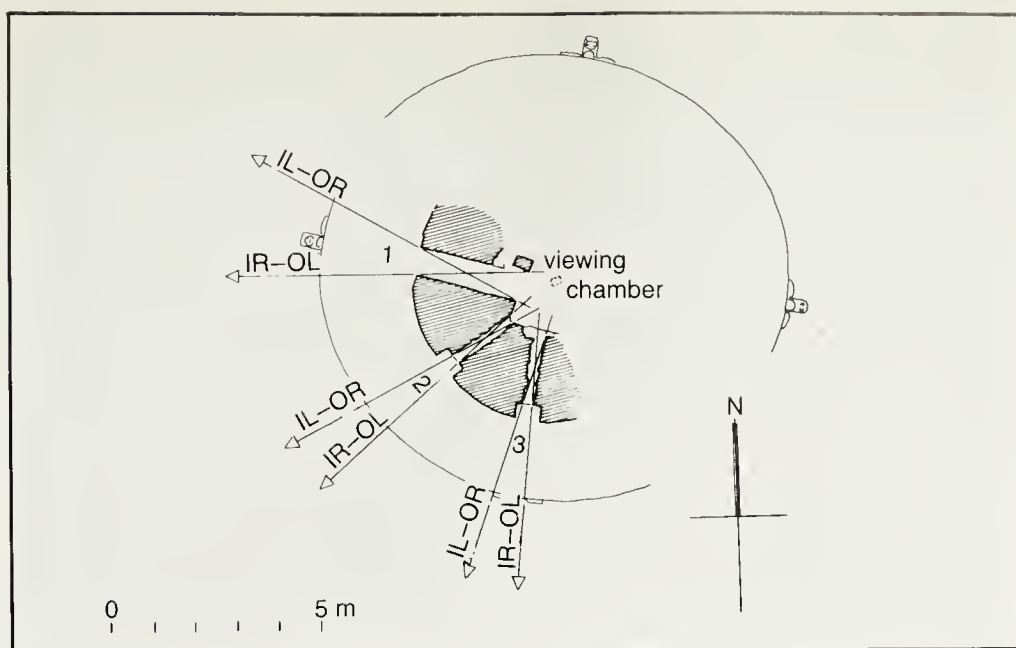


FIG. 91. Plan of the three surviving Caracol windows: (a) 1 IR-OL (inside right to outside left jamb): sunset at the equinoxes; (b) 1 IL-OR: Venus maximum north; (c) 2 IL-OR: Venus maximum south; (d) 3 IR-OL: an approximation to astronomical south or magnetic south (?); (e) 3 IL-OR: Achernar set. (Diagram by H. Hartung)

largest will accommodate a person attempting to crawl through. The other two slots are so narrow as to leave no doubt regarding their function. They were made to look through. The window jambs frame narrow segments of the southern and southwestern horizon. We know they could not have been intended to view distant cities since the directions to the nearest neighbor sites of any size bear no correspondence to the shaft angles.

When archaeologist Oliver Ricketson analyzed the building for astronomical orientations in the 1920s, he was drawn to these peculiar windows built into the tower. He hypothesized that diagonal sight lines, for example from the inside right to outside left jamb of a window, could have been employed to accurately pinpoint the position of a horizon event. Some of the alignments he suggested are sketched in the plan of the windows shown in Fig. 91. Recent measurements by me lend strong support to this hypothesis, particularly for the alignments of the inside left (IL) to outside right (OR) jambs of Windows 1 and 2. These directions precisely marked the northerly and southerly extremes of Venus along the horizon. Ricketson had suggested that the lunar extremes fit this pair of alignments quite well. In fact, the lunar standstills miss the mark by four lunar diameters in each case. At the northerly extreme, the moon would not even be visible to an observer stationed in the tower.

Another Caracol alignment suggested by Ricketson (1928) matches the sunset point at the equinoxes with a narrow strip of sky viewed along the IR-OL diagonal of Window 1. The sun still keeps its appointment there today, as Fig. 92 demonstrates.¹³ The vernal equinox marked the first day of the year that the sun could be viewed in Win-

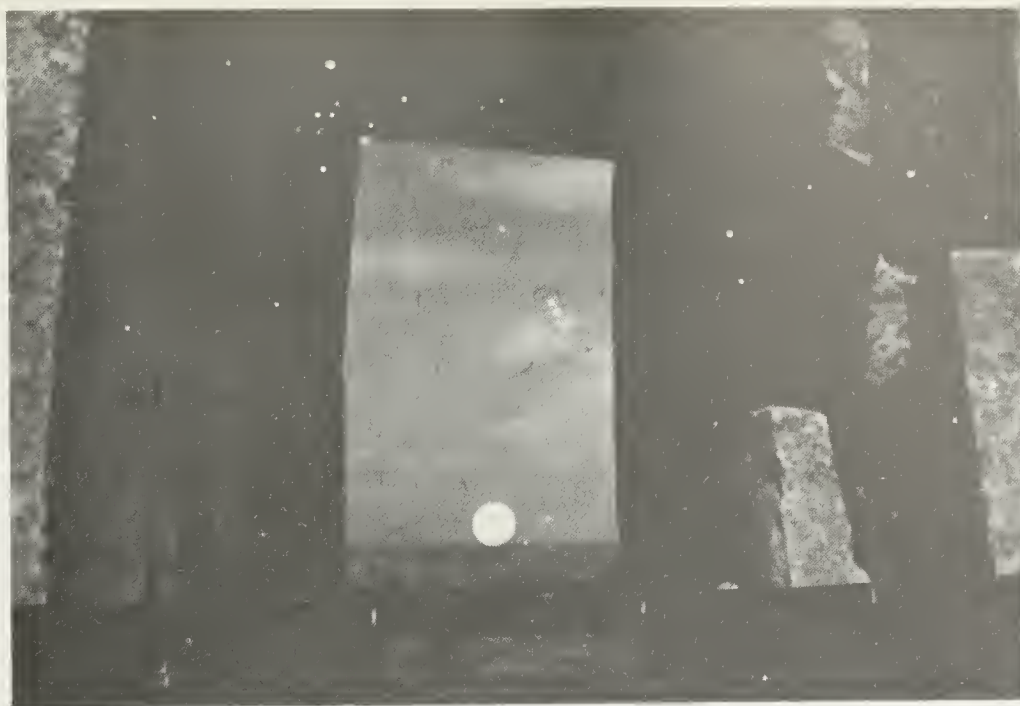


FIG. 92. The sun setting along alignment 1 IR–OL in Window 1 on the vernal equinox of 1974. The same alignment occurs six months later at the autumnal equinox at which time the sun returns to the Southern Hemisphere.

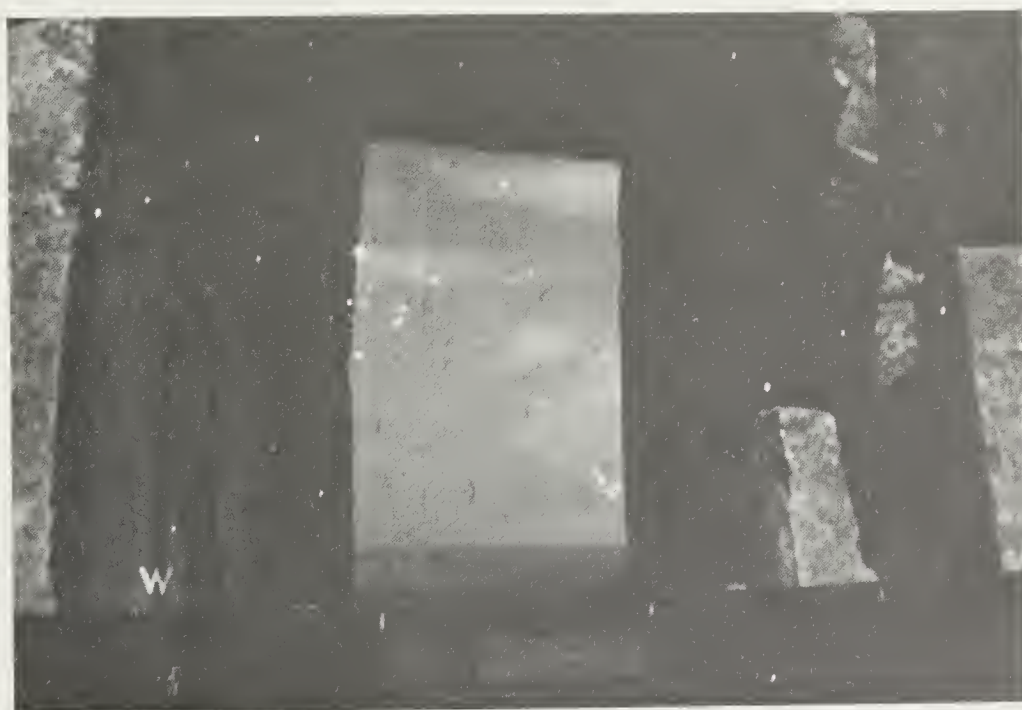
dow 1. Sunsets could then be witnessed there throughout the spring as the sun progressed northward; it passed the midline of the window on April 28. At the solstice turnaround, the sun would have been well to the right of the midline of the window but still a bit short of the Venus extreme, which marked the IL–OR diagonal; then it progressed southward, passing out of the window on the autumnal equinox. Ricketson suggested that impermanent markers on the window sill could have been used to chart the daily progress of the sun from equinox to equinox.

It is unfortunate that only the three windows (visible in Fig. 88c) at the western side of the building remain today. Archaeologist-explorer Alfred Maudslay, who visited Chichén Itzá late in the last century, tells us that the Caracol originally consisted of “an upper storey furnished with what looked like six small doorways facing outwards. Of these, the doorway immediately over the lower doorway—is the entrance to a small passage, three feet high, which probably passed right across the building to a doorway on the other side” (1889–1902, 3:21). Thus, Window 1 may have had its counterpart on the other side of the building to follow the all-important heliacal risings of Venus, as well as the solar sunrise path during the winter season. Since the building was already half ravaged before twentieth-century astronomers could make any measurements, we will never know the complete truth.

Another sight line worthy of consideration at the top of the tower is the IR–OL diagonal of Window 3. It points east of north to west of south and lies close to the present direction of the magnetic compass in northern Yucatán. Since the deviation of the compass needle from astronomical north is strongly time dependent, it would be dangerous



a



b

FIG. 93. A planetarium reconstruction of the view showing the sky as it would have appeared along the main axis of Window 1 in late April, about A.D. 1000. The appearance of the star groups in the window announced the forthcoming passage of the sun across the zenith.

to conclude that ten centuries ago it was the same as it is at present. However, there is some evidence to suggest that the Mesoamerican people may have known of the concept of a magnetic compass. At San Lorenzo, an Olmec ruin, archaeologist P. Krotser excavated a flattened oblong piece of magnetite with a longitudinal groove along one surface. Astronomer John Carlson (1975) determined that the bar, when suspended by a thread, consistently pointed toward magnetic north. He has concluded that the artifact very likely functioned as a compass. Moreover, it is interesting to note that many buildings in Yucatán align closely with the present direction of magnetic north. Such a fact prompts us to wonder whether the changing orientation of Maya buildings through time has a correlation with changes in the deviation of the magnetic compass. But see note 1 and Appendix E of Chapter III for a brief discussion of the migration of the magnetic pole.

When analyzing the Caracol windows for astronomical orientations, we must not overlook the possibility that they could have been intended for viewing entire constellations or star groups. The wide field of view from Window 1 (more than 20°) supports such a hypothesis. The problem can be studied quite satisfactorily using a modern planetarium. One of the results of such a study is shown in Fig. 93. It was produced by turning the clock back to A.D. 1000, the assumed building time for the top of the Caracol tower; setting the planetarium latitude for $20^\circ 41' \text{ N}$; and imaging transparencies of the windows against the western wall of the planetarium dome. The record depicted in the figure represents the sky as the ancient astronomers would have viewed it through Window 1 around the time of sunset on A.D. April 28, 1000, the day the sun crossed the exact midline of the window ("W" marks the west point of the horizon). In Fig. 93a the sun is tangent to the horizon at the bottom of the window. The Pleiades are visible to the upper right. With characteristic planetarium magic, we can view stars and the sun at the same time! Minutes later (Fig. 93b), the sun has set and the Pleiades begin to pass out of view at the lower-right jamb of the window. Consulting our heliacal tables (Table 10) we learn that in late April of A.D. 1000, the Pleiades made their last appearance in the west after sunset; they reappeared a few weeks later, undergoing heliacal rising in the east. Sunset on the midline could have been used to foretell the event. At the same time the V-shaped Hyades and Aldebaran, the bright red star in our well-known zodiacal constellation of Taurus, entered the window at the upper left. These stars were also given much attention in Mesoamerica.

The study of the Caracol has revealed a number of significant astronomical events which correlate with many of the measured alignments. Additional alignments of possible significance in the base of the building are depicted in Fig. 89. These include diagonals between doorways and lines between corner points on the Upper Platform, many of which coincide with the positions of important bright stars or solar horizon positions of possible significance.

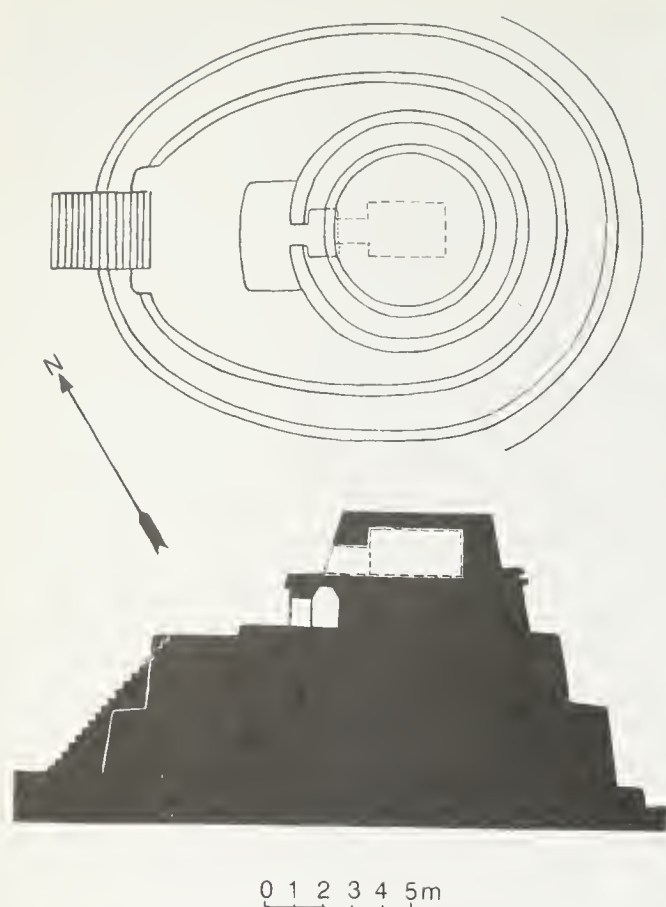
Though a matching astronomical event is not found for every alignment, nevertheless 20 of 29 preselected alignments actually fit reasonable astronomical horizon events. If a 69 percent success ratio seems unquieting, it should be remembered that, in the analysis, phe-

nomena were sought which we, as modern investigators, think may have been of functional importance to the Maya: solar, lunar, and planetary extremes on the horizon, positions of bright stars which announce, through their heliacal rising, important dates in the civil, religious, or agricultural calendar. While no grand cosmic plan for the architecture of the Caracol tower makes its presence obvious, modern studies of the building imply that, apart from being a monument dedicated to Quetzalcóatl-Kukulcan, the great tower was erected primarily for the purpose of embodying in its architecture certain significant astronomical event directions, in the same sense that a modern almanac exhibits information of importance to us in the keeping of the current calendar. The terrain of extreme northern Yucatán is absolutely flat. In a region where no natural landmarks exist to provide foresights for viewing the astronomical rise-set phenomena needed to devise a calendar, perhaps it is not so surprising to find astronomical sight lines embodied in the architecture. Here, indeed, was a Maya calendar in stone.

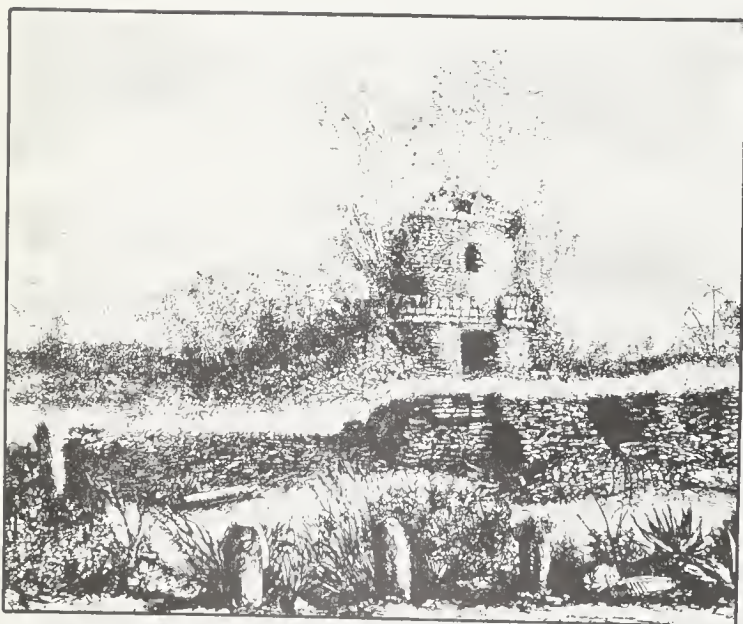
Other round structures exist in Mesoamerica. Though few are found in the land of the Maya, two large structures, one in the east of Yucatán and the other in the west, bear a tantalizing resemblance to the Caracol (Fig. 94). Furthermore, all three lie at the same latitude (see Fig. 94c for their locations). The great tower at Mayapán, that short-lived center of war and controversy, is the largest of five structures with a circular plan (Fig. 94b) at the Post-Classic capital in northwest Yucatán. Chronicler Diego de Landa tells us that the same Kukulcan who established Chichén Itzá also built this city and that he included a round temple with four doors in the plan:¹⁴

This Kukulcan established another city after arranging with the native lords of the country that he and they should live there and that all their affairs and business should be brought there; and for this purpose they chose a very good situation, eight leagues further in the interior than Merida is now, and fifteen or sixteen leagues from the sea. They surrounded it with a very broad stone wall, laid dry, of about an eighth of a league leaving in it only two narrow gates. The wall was not very high and in the centre of this enclosure they built their temples naming the largest which is like that of Chichen Itza the name of Kukulcan, and they built another building of a round form, with four doors, entirely different from all the others in that land; as well as with a great number of others round about joined together. In this enclosure they built houses for the lords only, dividing all the land among them, giving towns to each one, according to the antiquity of his lineage and his personal value. And Kukulcan gave a name to this city—not his own as the Ah Itzas had done in Chichen Itza, which meant the well of the Ah Itzas, but he called it Mayapan, because they call the language of the country *Maya*, and the Indians [say] *Ichpa*, which means “within the enclosures.” (1941, pp. 23–26)

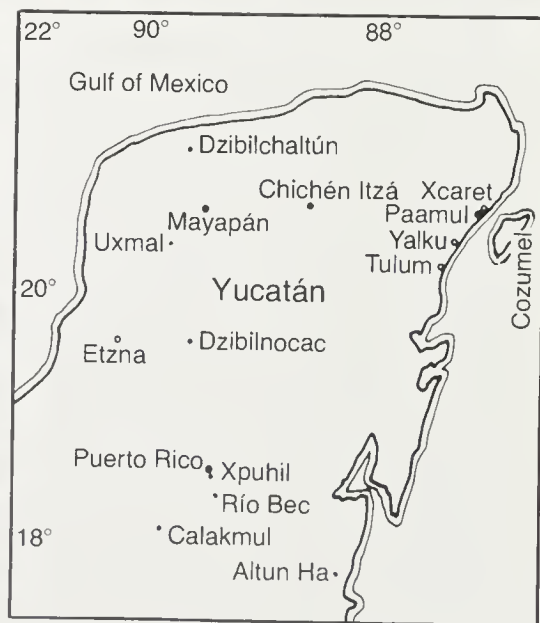
No description since Landa's time mentions four doors. In fact there has been much confusion over the original appearance of the



a



b



c

FIG. 94. Carbon copies of the Caracol observatory? (a) The Caracol of Paalmul in eastern Yucatán (Pollock, 1936, p. 116, courtesy of Carnegie Institution of Washington); (b) the Caracol of Mayapán in western Yucatán (*ibid.*, p. 111); (c) smaller round towers (*open circles*) abound in Yucatán; the four largest discussed in this chapter are shown as large, filled circles (diagram by H. Hartung).

building since it was nearly demolished by a lightning bolt in 1869. John Lloyd Stephens visited Mayapán and described its Caracol about thirty years before the catastrophe (a drawing by Catherwood accompanies the description in Stephens): "It stood on a ruined mound thirty feet high—the building was circular—the exterior is of plain stone ten feet high to the top of the lower cornice and fourteen more to the upper one. The door faces *west* and over it is a lintel of stone. The outer wall is five feet thick; the door opens into a *circular passage* three feet wide and in the center is a *cylindrical mass of solid stone*" (1843, 1:75–76; italics added).

French explorer Brasseur de Bourbourg obtained a sketch of the building from a photograph (Fig. 94*b*). Among the details visible are vestiges of a lower platform skewed relative to the principal doorway and a window in the upper portion of the tower above the entrance-way—both reminiscent of the Caracol of Chichén Itzá. Only the base of the lower platform of the tower is intact today. Transit measurements reveal that it is directed 13° north of west (cf. 27° N of W for the Caracol), but the upper portions of the tower could have been shifted considerably from this direction. Recall that the Upper Platform of the Caracol is skewed 5° relative to the larger basal platform beneath. Today no trace of a window or any other sighting shaft which may have been used to view the stars is detectable and even the access stairway leading up to the circular portion of the structure has been reduced to a shapeless pile of rubble. We can never hope to decide on the basis of the astroarchaeological record alone whether the Mayapán Caracol served the same function as the Caracol of Chichén Itzá. The basal orientation suggests that perhaps other astronomical phenomena were being sighted here. For example, Aldebaran, the bright red star in Taurus, set within 2° of the perpendicular to the base of the building. In the twelfth century, sunsets on April 28 and August 15 also match this direction. We recall that the former line coincides exactly with sunset along the midline of Window 1 in the Caracol of Chichén. If the window at the top were arranged to align with the base, then it may have been a duplicate of Window 1 of the Caracol. Our heliacal rise-set tables of Chapter III indicate that the Pleiades underwent last disappearance at Mayapán in late April. Furthermore, the sunset dates divide the year into 110- and 255-day periods at Mayapán, intervals which are close to the Copán astronomers' segmentation of the year into 260- and 105-day periods. Thus, there are many astronomical calculations which fit the architecture quite reasonably.

Considering the intensely warlike atmosphere in Yucatán at the time Mayapán was established as one of the regional Yucatecan capitals, we might suppose that the builders would give low priority to precise building orientation. To the contrary, we find that Structure Q-151, a building adorned with columns adjacent to the Caracol of Mayapán (Structure Q-152), is aligned to within 15 minutes of arc of its neighbor. The only other measurable circular structure (Q-214) at Mayapán also has its principal axis oriented within $15'$ of the 13° east-of-north direction. Like the remaining circular structures at Mayapán, it is a much smaller building bearing little resemblance to the Caracol except for its circular base plan.

The second large observatory tower, also of Post-Classic vintage, is located at Paalmul beach on the east coast of the Yucatán Peninsula opposite the island of Cozumel (Fig. 94a) and may have been the largest structure fronting the Yucatán channel with the exception of the Castillo of Tulum to the south. Archaeologist Gregory Mason described and photographed the building during an east coast expedition in the mid-1920s. His photographs and plan accompany one of the rare descriptions of the building found in print: "This Paalmul building is thirty-one feet eight inches [9.65]m high, but bigger than that measurement indicates, for it is roughly cone-shaped and has a considerable diameter at the bottom. It has four different walls or belts of masonry, looking not unlike four turrets of a battleship, placed one above another, the smallest at the top. The only room which we could find was a small one in the uppermost 'turret.' An altar at the back of this room had been broken, exposing crevices which ran down several feet" (1927, pp. 241–242). He goes on to speculate about the use of the building as an astronomical observatory and specifically mentions the Caracol of Chichén Itzá in a comparative statement. A short while later Nuttall (1930), seizing the stark parallel between the two buildings, proposed that an excavation at Paalmul be undertaken to accompany that already in progress at Chichén Itzá. Unfortunately, this never came to pass.

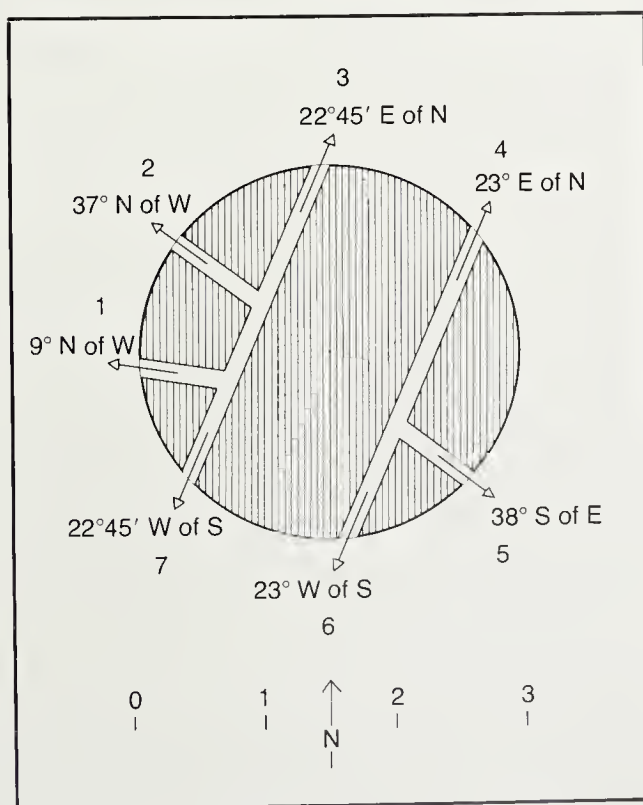
Fifteen years before transit measurements could be made on the building, it was almost totally leveled by a hurricane, having already been considerably eroded by the sea. Only the front wall of the upper façade is left standing today. Like the other Caracols, its orientation also lies to the north of west (azimuth = $303 \pm 3^\circ$). It is particularly odd that although the building is only 50 meters from the shoreline its façade is turned away from the coast. The Paalmul tower faces inland at about a 45° angle from the direction of the coastline. Of all the astronomical possibilities for its orientation, the moon at its northerly extreme setting position (azimuth = $300^\circ 48'$) comes closest to matching the direction of the façade. Pollux, the brightest star in Gemini the Twins, sets at azimuth $302^\circ 11'$. This star may have been significant since it underwent heliacal rising exactly at the summer solstice in the Post-Classic period. As in the case of the Mayapán tower, the argument for an astronomically motivated orientation remains uncertain since neither of the astronomical phenomena suggested for the Paalmul tower appears in the Caracol and a single measurement on a poor façade was all that could be obtained.

Provided we are not blinded by details, the common features of all three giant towers, as in the case of the cross petroglyphs, suggest that they were not simply perfunctory. The three share the same basic ground plan, identical latitudes, and a north-of-west orientation, all of which are consistent with a common purpose—to observe the heavens.

At Puerto Rico, a small site 240 kilometers south of Chichén Itzá on the northern edge of the Petén rain forest near Xpuhil, we find one of the most bizarre circular structures in all of Mesoamerica, one that totally defies any explanation to account for its origin. Photographs and a building plan are exhibited in Fig. 95. Archaeologist Wyllys An-



a



b

FIG. 95. Round tower at Puerto Rico: (a) one of the horizontal tubes is indicated by the arrow; (b) orientation of the sight tubes (diagram by H. Hartung).

drews IV (1968, p. 7) described the edifice as a solid cylinder of masonry pierced only by five horizontal perforations a little higher than the height of a man. These holes are just wide enough to accommodate a twin eye view through the tower. Built on a leveled-off portion of the building, the shafts were evidently constructed with great care for they are perfectly straight and dead level with the horizon. Accordingly, Andrews suggested that the building might have served some astronomical or astrological function, though his magnetic compass measurements of the alignments of the shafts bore no relation to any significant astronomical positions that he could find. My recent transit measurements of the directions of the shafts confirm Andrews' results.

Two parallel shafts equidistant from the center of the core exhibit the east-of-north skew common among so many alignments in Mesoamerica. Three other tubes enter the main shafts at angles of 75° , 76° , and 78° . We find that we must scour our astronomical tables of Chapter III to find anything significant about these directions. Only two astronomical alignments are found to fit the shafts and they correspond to the directions of the two longest tubes, both looking out to stars setting low in the southwest. Achernar fits one shaft and Alpha of the Southern Cross the other, but neither bears a special functional relationship to the solar calendar at the latitude of the site, thus weakening the argument.

Since the astronomical search seemed unsatisfying, the interesting possibility that the shafts might have been intended to point out the locations of other ancient cities was also examined. Four of the five orientations point in the general direction of major ruins too distant to be observed; one of them in fact is Chichén Itzá. Minor sites within a 20-kilometer radius of Puerto Rico are also a likely possibility, but positions for the multitude of ruined buildings in the immediate vicinity of Puerto Rico have not been determined with sufficient accuracy, given the overgrowth of vegetation in the area.

Another possibility also considered by Andrews suggests that the tubes were intended to be "psychoducts," or canals for communication with the departed spirits of the individuals interred beneath. (No excavations have been conducted in order to determine whether the tower was a funerary monument.) Such communication ducts are found in the Temple of the Inscriptions at Palenque and in the Temple of the Seven Dolls at Dzibilchaltún, but they are vertical not horizontal. Since the tower is solid all the way through, the possibility that the shafts could have been used for ventilation or drainage is also ruled out. Indeed, none of the arguments for the shafts proposed to date seems totally satisfactory. Consequently, the exact function of the circular tower at Puerto Rico must remain a total mystery to us, at least for the present.

Recently, studies of settlement patterns and hieroglyphic writing have combined to create a fascinating hypothesis that ties the ancient Maya view of the cosmos to architecture. Anthropologist Joyce Marcus (1976a), elaborating on an idea originally suggested by the German epigrapher Thomas Barthel, has suggested that cosmology may have played a significant role in the large-scale territorial organization of the Maya. In addition to the gods and colors, she believes that the Maya



FIG. 96. The Palace of the Governor, Uxmal.

constructed regional capitals symbolizing their four-directional view of the universe—preplanning on a truly grand scale.

Evidence for the grand-design theory comes from emblem hieroglyphs or place names of cities occurring together in the same inscriptional material. For example, Stela A at Copán displays hieroglyphs for the four world directions above the emblem glyphs that Marcus interprets for Tikal, possibly Calakmul, Copán, and Palenque, the regional capitals about 9.14.19.8.0, the dated inscription on the stela. As power shifted from one center to another, the capitals changed. So strong was the cognized model, she suggests, that, despite the rise and fall of individual centers, four capitals always seem to have existed (p. 911). Thus, a century later Copán and Palenque were replaced by Seibal and possibly San José. While the cities are not located precisely along the cardinal directions, they are taken to symbolize the world quarters.

On a smaller scale, Marcus proposes a more detailed geometrical scheme based on the central-place theory of German geographer W. Christaller (1933). Each capital appears to be surrounded by a grouping of nearly equally spaced secondary centers arranged in a hexagonal pattern (some investigators see a square plan instead). Each secondary center serves as the focal point of a tertiary cluster, again arranged in the shape of a hexagon. (She has recently been criticized for applying Christaller's scheme in too detailed a manner [Turner and Doolittle, 1979].)

Even before Marcus suggested the latticelike arrangement for the placement of Maya cities, certain peculiarities in the plan of Uxmal had already suggested that the arrangement of at least one of the major buildings at that great Maya center influenced the precise placement of a secondary ceremonial complex nearby.

Most of the structures at Uxmal, one of the largest sites in northern Yucatán, are oriented 9° east of north. A notable deviant from the plan is the so-called Palace of the Governor pictured in Fig. 96. It also

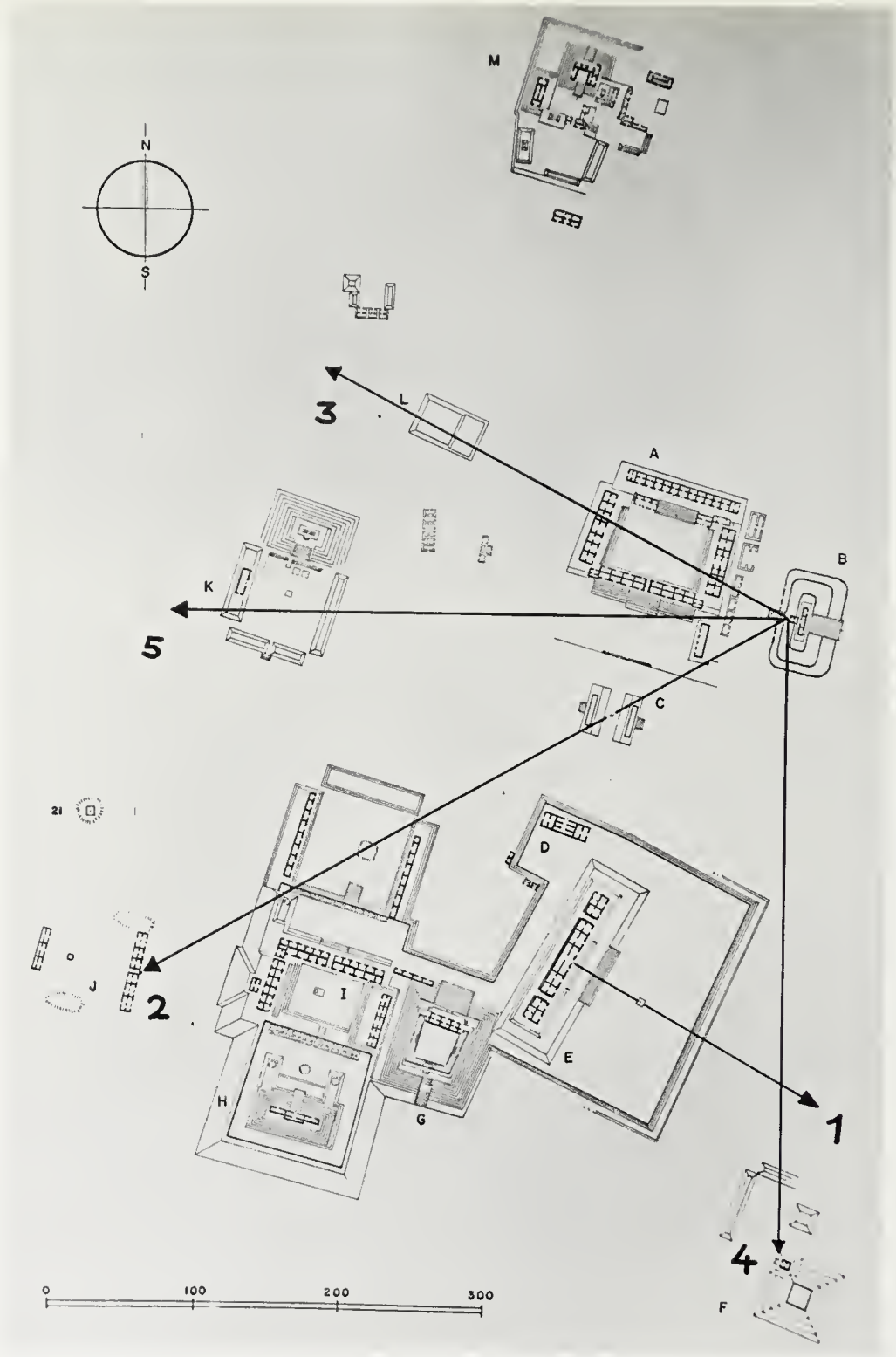


FIG. 97. Plan of Uxmal showing astronomical placement of buildings. (Diagram by H. Hartung)

stands out (Building B) in the ground plan of Uxmal, presented in Fig. 97. This building, regarded as one of the finest examples of the Puuc style of Maya architecture, is erected on an elevated artificial platform skewed 19° clockwise from the common axis of the buildings so that it faces 28° south of east. From its central doorway, precisely along a perpendicular to the façade (line 1 in Fig. 97), one can see the only noticeable feature along the horizon: an artificial structure several kilometers distant. Fig. 98 shows the view from the central doorway of the Governor's Palace in a photograph procured with a telephoto lens. Only a poor untraveled path makes its way to these ruins from a highway passing a few kilometers to the west. Once cleared, the mound revealed its pyramidal shape and immense size. It stands over 25 meters high among a surprisingly large field of ruined mounds which rival the largest structures at Uxmal in both volume and height. Stephens, that indefatigable explorer, had been there over a century ago and he learned that the name of this place was Nohpat. He describes the ruins and the inspiring view looking westward toward Uxmal:

With the ruins of Nohpat at our feet, we looked out upon a great desolate plain, studded with overgrown mounds, of which we took the bearings and names as known to the Indians; toward the west by north, startling by the grandeur of the buildings and their height above the plain, with no decay visible and at this distance seeming perfect as a living city, were the ruins of Uxmal. Fronting us was the Casa del Gobernador, apparently so near that we almost looked into its open doors and could have distinguished a man moving on the terrace; and yet for the first two weeks of our residence at Uxmal, no part of it was visible from the terraces or buildings there. (1843, 1:221)

Transit measurements on the perpendicular from the doorway of the Governor's Palace indicate that it points not only to the principal pyramid of Nohpat but also exactly to the position on the eastern horizon where Venus would have risen at the time of its maximum southerly eight-year excursion about A.D. 800 when the Palace of the Governor was erected. Moreover, the sculpted frieze on the Palace includes more than 350 Venus symbols that adorn portions of the decorative masks on all sides of the building. The construction of the Uxmal-Nohpat axis occurred at about the same time the Maya were laboring on the Lower Platform of the Caracol at Chichén Itzá, fixing it to align precisely with another important position of Venus on the horizon which could be employed in the construction of the calendar. Apparently, the invading Toltecs shared the Maya's regard for the planet Venus. At Chichén Itzá they manifested this interest architecturally in a circular building rather than in a large rectangular structure like the Palace of the Governor at Uxmal. In the case of Temple 22 at Copán they used a single narrow slot in a rectangular building. The Uxmal-Nohpat astronomical relation directly supports the hieroglyphic and geographic evidence that cosmology, in particular the planet Venus, played a major role in the large-scale territorial planning of the Maya.

Present-day residents of the village of Santa Elena, just east of the

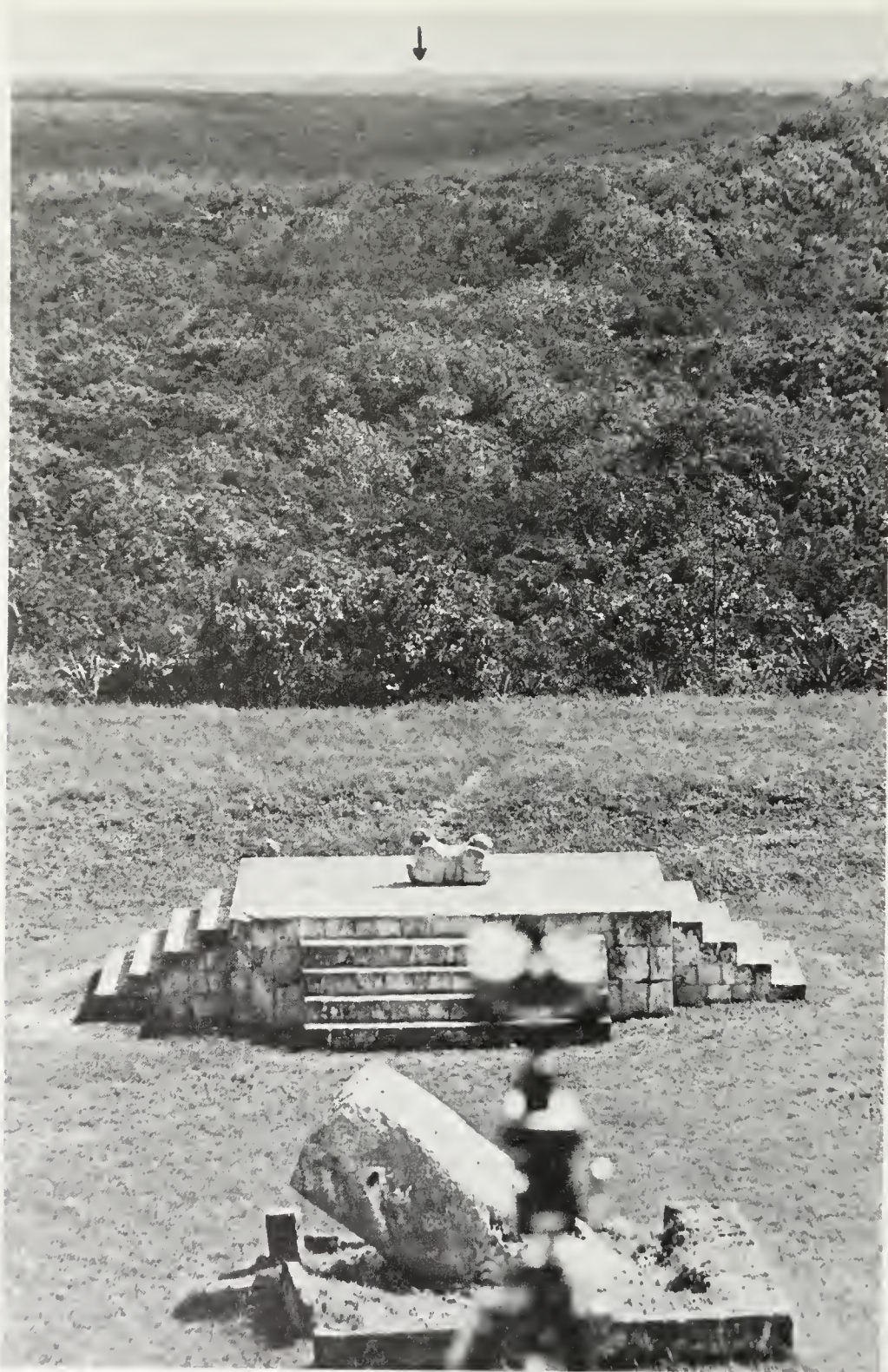


FIG. 98. The ruins of Nohpat: telephoto view along a perpendicular from the doorway of the Palace of the Governor at Uxmal.

highway near Nohpat, repeatedly emphasized to me that other ruins were visible along the distant horizon from the top of Nohpat's highest pyramid: Mul-Chic to the southeast, Xcoch to the northeast, Huntochac to the northwest. Kabáh, a major site 15 kilometers to the south-southeast, was the most distant. It can be viewed from the Nohpat

ruins alternately rising and falling on the distant daytime skyline, a shimmering mirage created in the heat of the sultry Yucatán afternoon. The vista from any one of these lofty pyramids seems suggestive of that depicted in a map dated 1557 and published in Stephens' second volume on his Yucatán travels (Fig. 99). In both cases the horizon seems to be the fundamental environmental reference plane. The map, originally attributed to the Xiu family, who governed the Puuc territory both before and long after the conquest, shows the city of Maní at the center. Regularly spaced in a geometric pattern along the horizon on the rim of the circular sketch are thirty-two distant Yucatecan cities, each apparently signifying a particular reference direction from Maní. In between we see a diagram showing how the lands were apportioned in order to determine village rights regarding the felling of trees, pasturing of cattle, and so on.

Other features of the Uxmal plan delineated in Fig. 97 suggest that the relative placement of buildings within the city also may have been determined astronomically. The Cemetery Group plaza (K) is situated almost exactly west of the House of the Magician, or Dwarf (B) (line 5), while the House of the Old Woman (F) is almost due south (line 4). The last gleam of mid-summer sunset coincides with a line passing from the House of the Magician over the geometric center of the Nunnery Quadrangle (A) (line 3), and, finally, a straight line from the House of the Magician passes through the exact centers of three consecutive structures, including a ballcourt. It strikes the Venus set position at maximum southerly declination (line 2). These observations clearly demonstrate that we have only begun to understand the cosmic blueprint which governed the structure of Uxmal and surrounding sites. We must be careful not to attribute too much to the preplanning of ceremonial centers necessitated by astronomical or religious values, seeking alignments everywhere we go. On the other hand, a pure socioeconomic or marketing-trade approach to the study of site location and planning will not give all the answers either, particularly when the sacred space associated with an ancient city is under discussion. Indeed the truth must arise out of the interdisciplinary study of concrete and spiritual forces operating in the minds of the builders.

Another unusual complex occurs at Uaxactún, a large site in the Petén rain forest of Guatemala 12 kilometers north of Tikal. Some of its structures were erected as early as baktun 8. It may be recalled from our earlier discussion that three cross petroglyphs of nearly identical design compared to those at Teotihuacán appear in one of the buildings there (Str A-V). Their axes take the same orientation as the petroglyphs in the Teotihuacán ceremonial center. Among the curious specialized assemblages of Maya buildings, the Group E arrangement at Uaxactún may have been utilized exclusively for solar observations, accompanied perhaps by an attendant ritual associated with the keeping of the solar calendar. An astronomical function for the Group E buildings was first pointed out by archaeologist Frans Blom in 1924. From the top step of Building E-VII sub, a pyramidal structure, one looks out toward the east over an open plaza (Fig. 100). In the foreground lie the remains of three small buildings constructed on a single platform, the outside ones (E-I and E-III) equidistant to the north and south of the central

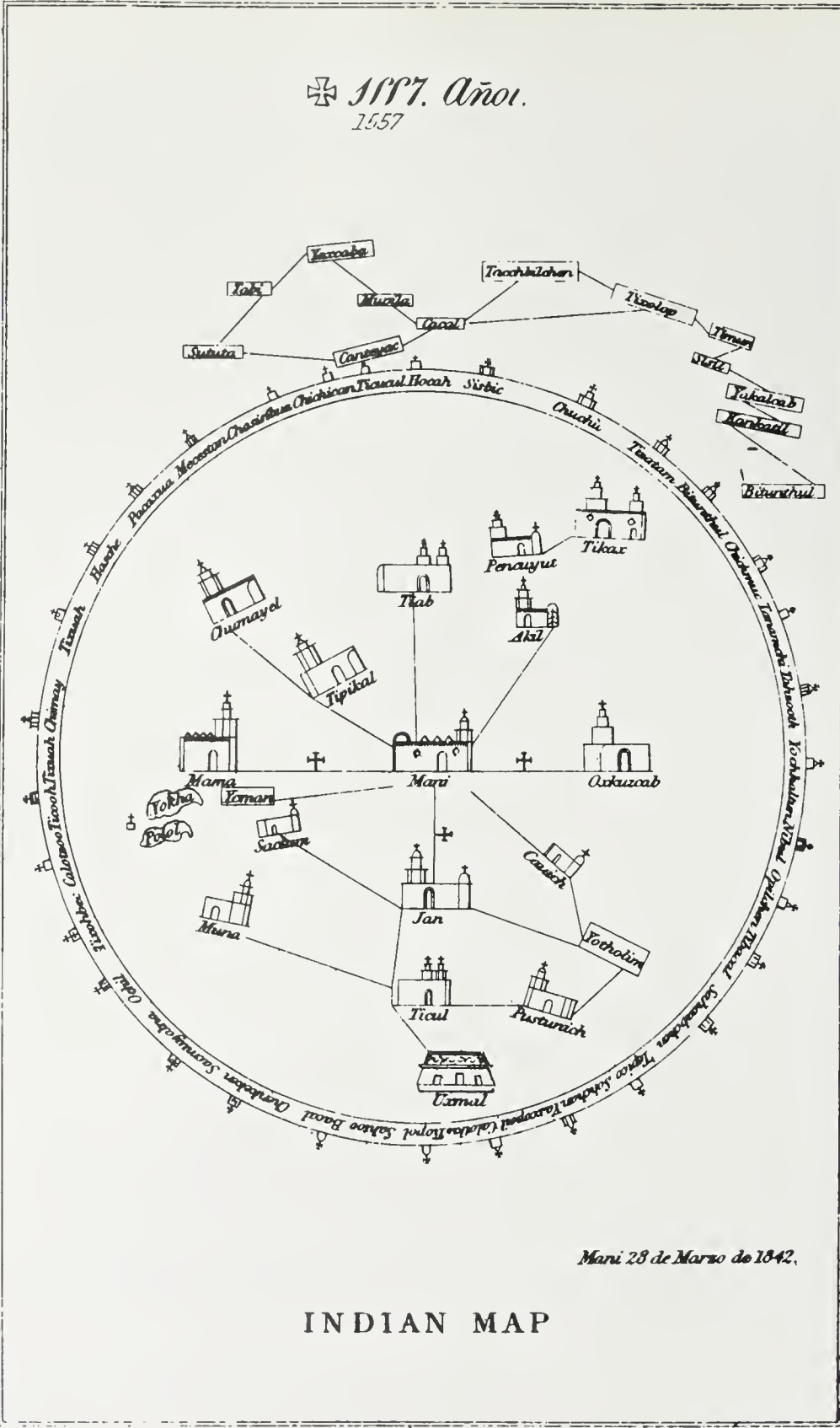


FIG. 99. Map showing the arrangement of neighboring towns about the horizon of Maní, at the center. (Stephens, 1843, 2:173)

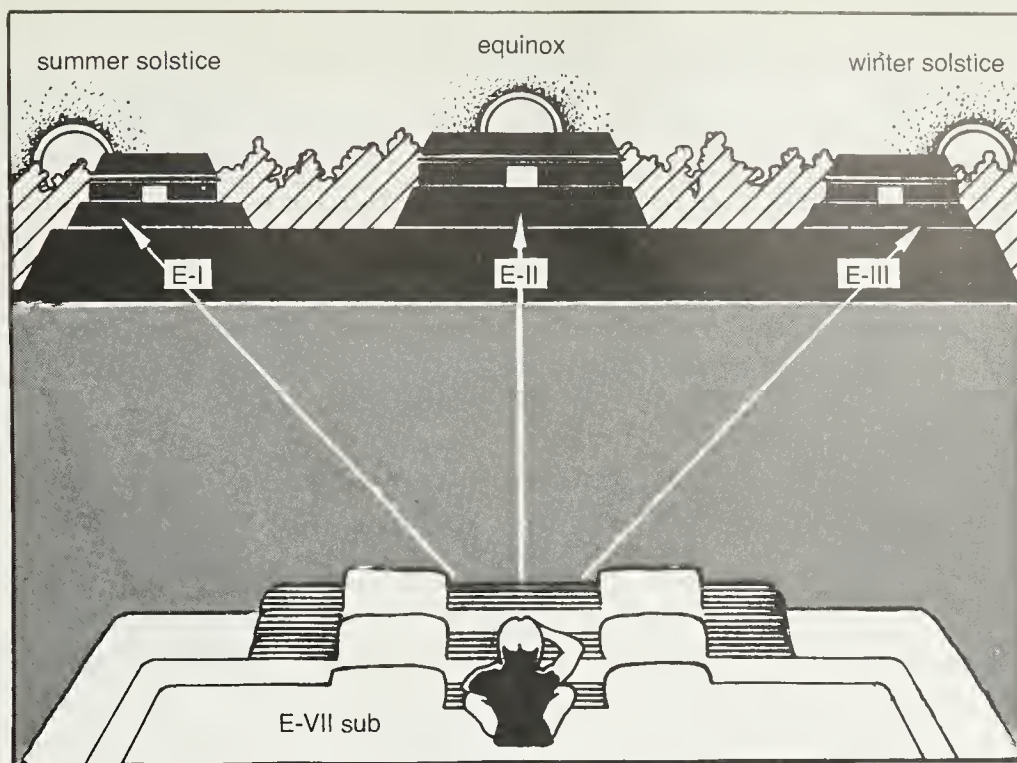


FIG. 100. Group E solar observatory, Uaxactún. (Diagram by P. Dunham)

building (E-II), which is situated exactly east of the observer. Blom noted that the sun rose approximately above the northern mound on the first day of summer, over the southern mound on the first day of winter, and transited the central mound at the two equinoctial dates.

Given the observer's vantage point on the west side of the plaza, the eastern buildings at Uaxactún align very accurately with key solar positions. Archaeologist Oliver Ricketson (1928) later proved that, if the viewpoint from the top of the pyramid be shifted to a position on its stairway fifteen feet above the level of the plaza, the lowest point from which the horizon could be viewed over the eastern buildings, the bearing of the northwestern corner of the central building would coincide exactly with the sunrise on the same dates indicated by the Copán base line. Furthermore, this position also corresponds to the location of the central doorway of an earlier structure, E-VII sub, which lay buried beneath E-VII and was probably the original pyramid used to establish the sighting scheme.

There are three stelae in the Group E complex bearing katun ending dates as follows:

Stelae 18 and 19	8.16.0.0.0
Stela 20	9.3.0.0.0

Interpreted according to the Spinden correlation, the equivalent dates in the Christian calendar, A.D. April 5, 97, and A.D. April 3, 235, correlate surprisingly well with the measured base line. The edges of building E-II mark sunrise positions on April 6 and September 5. This fact, along with the agreement between Spinden dates on Stela 10 and Altar U at Copán with the day of sunset along the Stela 12–10 base line, sug-

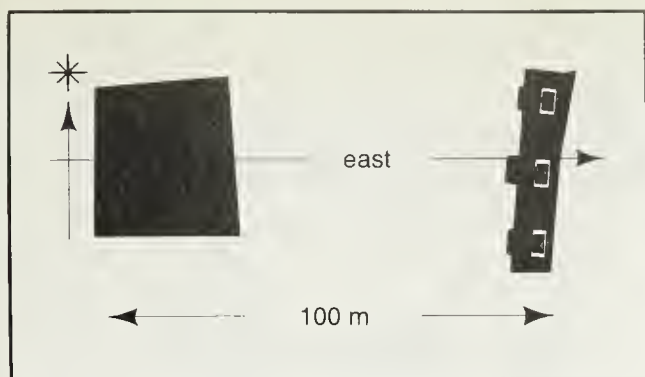
gests that the Spinden correlation ought not to be considered obsolete in all quarters, as now seems to be the case.

Curiously, the Uaxactún orientation problem never seemed to have been attacked on the basis of astronomically determined alignments until 1978, when we took transit readings from Ricketson's sighting point on E-VII sub. We found the alignment to the equinox sunrise over the top of the middle building, E-II, to be in error by only $0^{\circ}30'$, or about one sun's disk. Considering the rapid movement of the sun at the equinoxes (see Table 2), this result seems quite satisfactory. Alignments to the solstice points over E-I to the north and E-III to the south are a bit more problematic given the poor conditions in which we found those structures. Our best determinations of where the sun would have risen relative to the corners of those buildings yield errors of only $0^{\circ}32'$ and $0^{\circ}44'$, respectively. More significantly, having made measurements to complex E-I, E-II, and E-III from six different points on E-VII sub, we found Ricketson's observation point to correspond to the best choice for an observatory in that it gave the most accurate readings over the triplet of structures on the east side of the plaza.

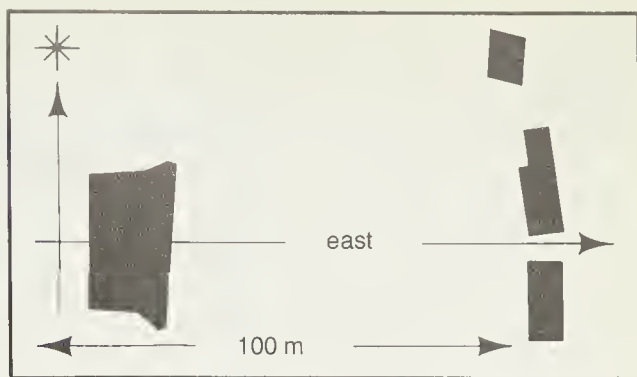
Apparently, the Group E arrangement was copied in the architecture of at least a dozen sites within a 100-kilometer radius of Uaxactún. Imitation Group E structures have been discovered at the ruins of Nakum, Naachtún, Yaxhá, Uxul, Benque Viejo, Ixkún, Río Bec, La Muñeca, Cahal Pichik, and Dzibilchaltún (Fig. 101). Rathje (1973) has linked their florescence in the central lowlands with the demands for a better calendar emanating from a developed trade model in the region.

A close examination of the "Group E-Type" structures at these outlying sites by archaeologist Karl Ruppert (1940) led to the conclusion that most of the arrangements were nonfunctional copies of the working-model solar observatory at Uaxactún, perhaps diffusing outward from their origin in the same way the pecked crosses spread beyond Teotihuacán. In many instances (e.g., Naachtún, Fig. 101a) the buildings were erected slightly out of symmetry with respect to the cardinal points. Often more than three structures were built on the eastern platform, though the three primary buildings were easily distinguishable since they were higher than the others. At La Muñeca (Fig. 101b) the eastern group of buildings is further distorted, and at Cahal Pichik (Fig. 101c) the arrangement is so misshapen that even a vague derivation from the Group E arrangement at Uaxactún is debatable. In all but one of twelve sites studied by Ruppert, the long axis of the eastern buildings shows the familiar deviation to the east of the north-south line. The other cities may have paid more attention to the ritual and less to the associated astronomical observations, so that the general planning scheme was adopted from Uaxactún but strict adherence to the proper orientations was abandoned. In these cases the structures seem to have served a geomantical rather than an astronomical function.

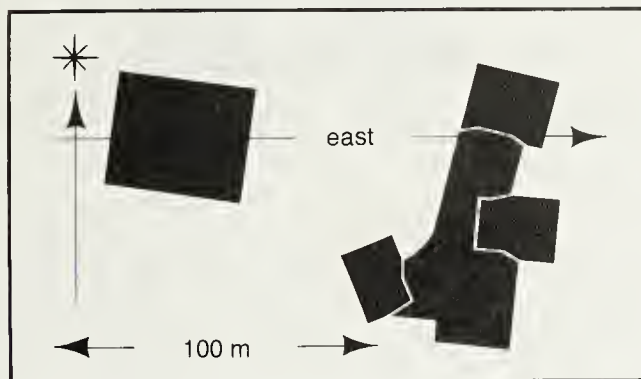
At Dzibilchaltún, well north of the Petén region (Fig. 101d), we find another possible Group E arrangement. Here the structures are reversed, with the observer standing in the doorway of the House of the Seven Dolls on the east side of the plaza and looking west. Again the north-south axis of the triplet of buildings—I, II, III—is rotated east of north (by 3°). The Dzibilchaltún solar observatory is functional only if



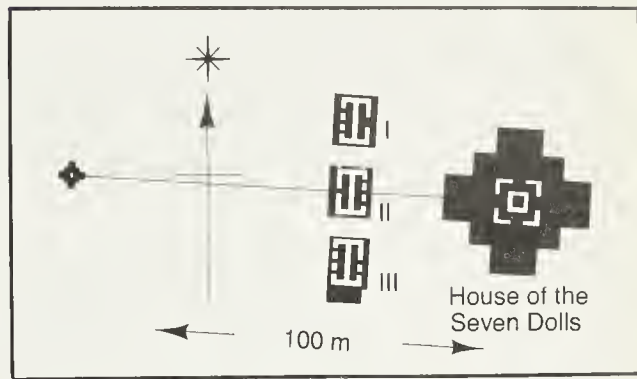
a



b



c



d

FIG. 101. Other sites in the Petén of Guatemala exhibiting the Group E plan to progressively greater extremes: (a) Naachtún (after Ruppert, 1940, p.226); (b) La Muñeca (ibid, p. 231); (c) Cahal Pichik (ibid., p. 229); (d) Dzibilchaltún. (Diagrams by P. Dunham)

we allow the builders errors of three to four days in determining the solstitial and equinoctial horizon points. The general form and arrangement of the buildings as well as the east-of-north deviation cannot be coincidental.

Today the Ixil people of Guatemala still mark the sun on the horizon with great care, thus keeping alive the art of calendar keeping practiced by their skilled ancestors (Fig. 102). In the 1940s anthropologist Steward Lincoln sketched and described in one of his note books (unfortunately all too briefly) an unusual contemporary solar observatory at Nebaj, a village near the Guatemala-Honduras border. R. C. E. Long (1948), who studied Lincoln's field notes shortly after his untimely death, quotes one of them (p. 214): "Observations of the sun are made at the stone today by zahorins for planting and harvesting" reads the statement accompanying a sketch which shows a line of sight extending from an observation point over a distant vertical stone (a back-sight?) to an indentation in the hill east of the village where the sun rose (OS). At the same time a second line (PS) passed over another stone to the same indentation. It was probably used by another observer so that greater accuracy could be achieved in fixing the alignment, which must have been directed to the solar equinox since Lincoln gives the date of the observation as March 19. A careful series of



FIG. 102. Sighting scheme used in a contemporary "observatory" of the Ixil people of Guatemala. (Diagram by P. Dunham)

daily observations in the few days around the equinox, when the sun undergoes sizable shifts on the horizon, could be used to fix the start of spring or autumn with great accuracy. Other stones which may have figured in the observations lie in the angle between the two lines.

The old method of date keeping (alternating 13 numbers with 20 names) still practiced by the Ixil shows that only certain days are favorable for work in the fields, and Lincoln is careful to note that concerning the planting of corn "all worked fast and finished that day." Also, he was told that one of the days favorable for killing a turkey occurred just one uinal and three days after March 19 of that year. It is possible that after the day of the observation of the equinox at least one uinal must expire before this act could take place.

The scheme involving a double sight line to a single fixed point on the horizon is reminiscent of that used at Alta Vista to sight the sun on the summer solstice and at the vernal equinox from two different observing stations (see Fig. 72*d*). The Nebaj arrangement also calls to mind the Hopi practice of viewing the sun positions against natural landmarks (see Fig. 13) and the methods for positioning objects on the horizon with crossed-sticks (Fig. 5), except that the modern Maya seemed to be using a backsight for greater accuracy. Lincoln's detailed study of the Ixil calendar was reported in 1942.

Archaeologist Edwin Shook has noted similar archaic arrangements of stones at Monte Alto and Finca Naranjo, both near modern Guatemala City; he was kind enough to allow Sharon Gibbs and me the use of his unpublished field notes on these places. The operation of neither of the aforementioned sighting schemes seems clear. The latter (Fig. 103) consists of a centrally located stone (marked f) with a 3-foot hole cut through its center. The aperture is large enough to admit the head of a man all the way to the shoulders. The part of the hole facing east is cut so that the face must be horizontal when the head is passed through. A 300-foot-high, cone-shaped mound (not shown) is situated due east of the stone; a line of small mounds arranged on a north-south

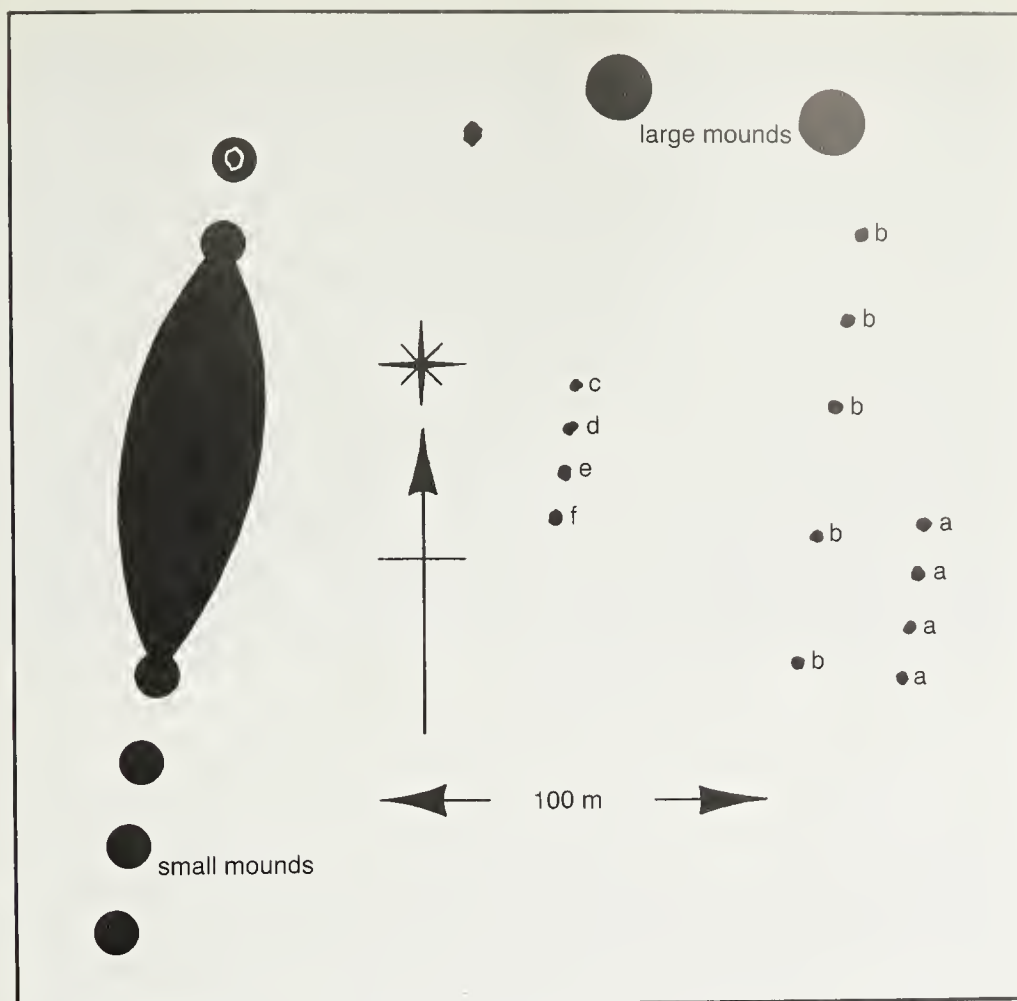


FIG. 103. Plan of Piedra Parada, Finca Naranjo, Guatemala: an array of stones possibly used to mark solar horizon stations. (Diagram by P. Dunham after Williamson, 1877, p. 62)

axis lies to the west. Other lines of stones ranging in size from small boulders to masses 5 feet high dot the open field which spreads out on a plain over 600 yards wide. All are arranged in neat rows of four to six on north-south lines. Shook believes that these are intended as observation points or backsights to be used on different days of the year just as in the Nebaj alignments.

The Nebaj evidence, along with the recent discovery of the Chamula calendar board (see Chapter II), demonstrates that the old Maya calendar still lives five centuries after the conquest. In Nebaj we are witnessing the practice of correction to the calendar by direct observation on the landscape, no doubt a common activity in the area a millennium ago, when timekeeping was the focal point of the civilization and the calendar, replete with correction tables, was displayed in the Maya codices.

In his *Calendario Maya-Mexica*, Guatemalan ethnologist Rafael Girard (1948) discusses a number of solar observatories still extant near Esquipulas on the Guatemala-Honduras border. Here the Chorti people follow the solar calendar by employing natural markings in the local

topography to signal the different positions where it will rise and set. For example, one observatory at Peña de Cayaguarca consists of a platform from which the local shaman can observe the winter and summer solstice sunrise positions as well as sunrise on February 8, an important religious date. But the most important point worth registering in the landscape is the sunrise point on the date of passage of the sun through zenith. In the temple at Esquipulas and in another one nearby, the principal line of symmetry of the observatory is the zenith sunrise line, which figuratively takes the place of the cardinal direction east. Named peaks on the horizon indicate the solar extrema and the equinox sunrise position.

If Uaxactún in the past and Nebaj in the present represent the extreme in astronomical accuracy, Palenque is typical of the subtle transition found between architecture erected for a specific astronomical purpose and that which is related to the heavens in a purely symbolic way—an astronomical hierophany.

Once the western Maya capital and regarded as the entrance to the Maya underworld, this impressive center exhibits a complicated and confusing plan, owing partially to its situation on the side of a hill at the edge of the rain forest. But astronomical hierophanies may have played a decisive role in the emplacement and orientation of many of the major buildings. Art historian Linda Schele (1977) sees a dramatic connection between the three-story square tower in the Palace complex, often called an observatory, and the Temple of the Inscriptions (TI) 100 meters to the southwest. The latter is the funerary monument of Lord Shield Pacal, ruler of Palenque when the city was at its zenith about 9.9.0.0.0. His remains, bedecked with jade and a death mask, were found in an elaborately sculptured sarcophagus in the crypt below the foundation in 1952. On December 21, the setting sun viewed from the tower plunges into the Temple of the Inscriptions as it “enters the underworld through Pacal’s tomb” (p. 49). The angle of entry is approximately the same as that of the stairway leading down to the tomb. The hierophany signifies the transfer of power of the deceased Pacal to his son, Lord Chan Bahlum. Schele’s studies of Palenque iconography strongly suggest a transfer of power from father to son at the critical instant when the sun passes between the middle world and the underworld (at sunset): “. . . the winter solstice sun enters the underworld through Pacal’s tomb, and the event portrayed symbolically on the sarcophagus lid is reproduced literally on each winter solstice” (p. 49).

Schele finds another potential winter solstice hierophany occurring at the Temple of the Cross, the accession monument of Chan Bahlum. As she describes it:

The site is arranged in such a way that, when the sun disappears behind the inscriptions ridge, the main center—including the TI, Palace, Temple II, etc.—is covered with an advancing shadow . . . A depression in the ridge allows the sun at the same time to shine fully on the Group of the Cross. The effect is very much like a spotlight. The sunlight falls at an oblique angle across the front of the Temple of the Cross and, because of the placement of the TC, it is only at this time of the year that direct sunlight ever

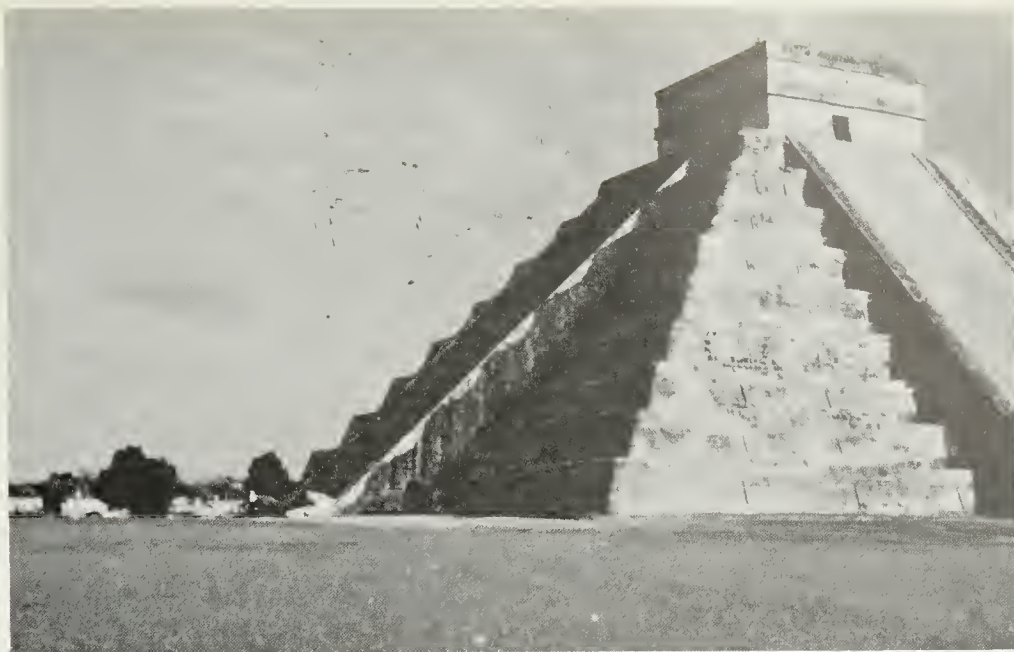


FIG. 104. Equinox hierophany of the Castillo at Chichén Itzá.

hits the front of the temple or its interior . . . The piers in front are arranged in such a manner that pier b . . . casts a long oblique shadow creating a shaft of light adjacent to it. As the sun sinks lower, the light is isolated onto God L. If the lintel over the pier were in place, the shadow would form an angled light terminating near the top of the God L jamb. The shaped light travels down the jamb toward the lower right-hand corner. The last direct sunlight of the winter solstice to hit the main center falls on the feet of God L.

The two hierophanies are arranged to occur successively beginning at about 2:30 P.M. and concluding at about 5:30 P.M. In both cases the events are extraordinarily vivid and must have been designed to reproduce the occurrences portrayed symbolically on the tablets. (Pp. 49–50)

The subtle influence of light and shadow upon Mesoamerican architectural design has been given very little attention. Another possible hierophany occurs in the architecture of Chichén Itzá. J. Rivard (1970) describes the events occurring at the Castillo as the sun sets on the equinoxes (Fig. 104 illustrates).

About an hour before sunset on the vernal and autumnal equinoxes the nine platforms which make up the pyramidal base of the Castillo cast thin shadows on the balustrade wall of the north stairway in such a way as to form an undulating line similar to the one used in so many building decorations of this area.

The union of this serpentine line with the large ophidian head found at the base of the northern staircase presents a striking picture of a serpent of light. . . . To the ancient peoples who worshipped at this site a manifestation such as this must have

seemed a most awe-inspiring hierophany since the serpent was one of the meaningful aspects of their religious experience. (Pp. 49–50)

How far can the Castillo hierophany be carried? Rivard goes on to speculate that after the serpent descends the stairway he moves in the direction of the sacred cenote to the north. The well was considered the home of the Rain God, symbolized by a serpent. He also indirectly ties other buildings representing Venus and the underworld into the relationship.

The Palenque and Chichén Itzá hierophanies are difficult to test with any astronomical accuracy. After all, their symbolism was intended to be purely mythological. These arrangements are so broadly structured that they could never have been intended to serve as a basis for collecting calendric observations of the type we find delineated in the codices; nevertheless, these architectural hierophanies, which find their phenomenal origin in astronomy, provided some of the most powerful religious experiences the common person could witness in the environment of the ceremonial center.

ASTROARCHAEOLOGY OF NORTH AND SOUTH AMERICA

We close with a brief discussion of astroarchaeology in North and South America, the borderlands of Mesoamerica, where a far less complete record indicates that the intensity and sophistication of the sky-watcher's craft, though not well developed, was a vital part of the culture. In the case studies to be reported, we discover a number of ingenious schemes for establishing astronomical sight lines connecting works of human origin with the landscape. Some of the methods employed are found to be similar if not identical to those that occur in ancient Mexico, thus suggesting that certain astronomical practices may have diffused from the high cultures to developing civilizations on the periphery of nuclear Mesoamerica.

Astronomer John Eddy (1974) has given a complete review of astronomical practice north of the Rio Grande. His hypothesis about the possible astronomical use of the Big Horn Medicine Wheel, so named because of the resemblance of its plan to that of the medicine lodge, has revived some recent interest in this area. Eddy's studies suggest that the Native North Americans not only marked rise and set positions very accurately but also went about it in a manner similar to that of their southern neighbors. Big Horn (Fig. 105) is one of three dozen spoked wheels fashioned out of chains of large boulders. Dating from the last half millennium, these curious earthworks are located along the Rocky Mountains of Wyoming, Montana, Alberta, and Saskatchewan. Typically 5 to 15 meters in diameter, medicine wheels display a circular pattern along the periphery of the spokes; some exhibit stone cairns at the center or along the axes. Like the lines on the plains of Nazca and on Building J of Monte Albán, these structures become particularly conspicuous when viewed from the air. Unlike the Nazca patterns, however, all medicine wheels are located on mountain tops.

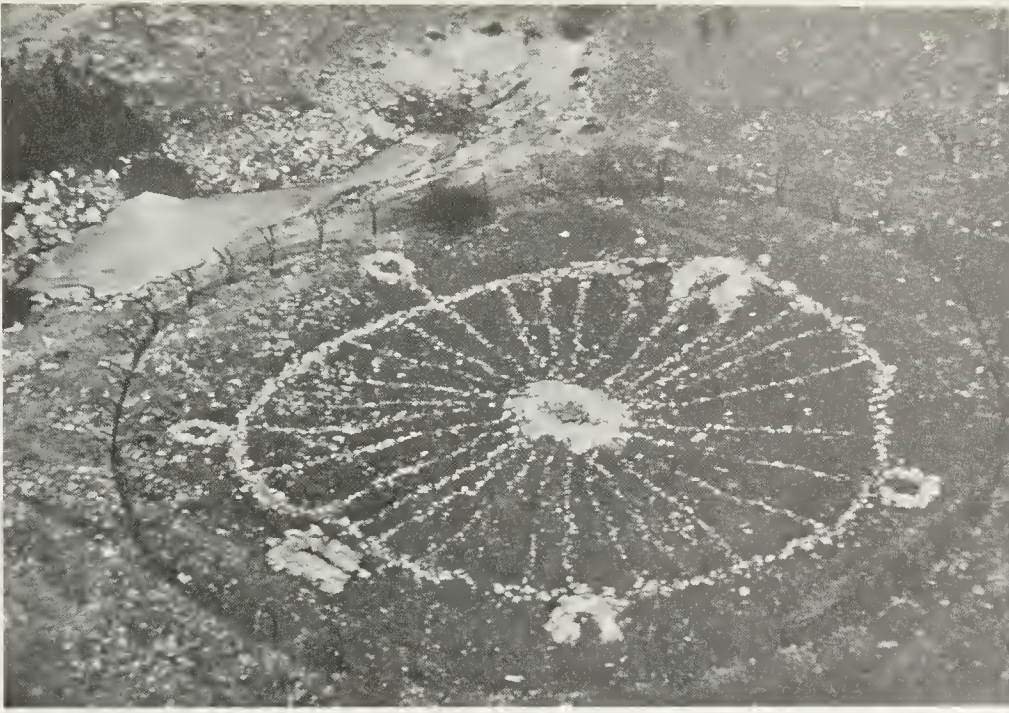


FIG. 105. Big Horn Medicine Wheel, Wyoming. (Courtesy of USDA Forest Service)

Eddy's study of the Big Horn alignments has yielded some impressive and convincing results, all of a functional nature. The orientational significance is illustrated in the map of the wheel in Fig. 106. The sight lines between cairns seem to have possessed a functional nature: they aligned with stars which rose heliacally on key dates during the year. The line between cairns F and A points to the rising position of red Aldebaran, and that between F and B to blue Rigel in Orion. Using cairn F as backsight and C as foresight, one can view Sirius on the horizon. All three were prominent stars which rose in the predawn summer sky, the only time the wheel could be used, since raging snowstorms plague the Big Horn Mountains during the remaining nine months of the year. More importantly, the heliacal rising of each of these stars occurred at one-month intervals. Taken in turn, they marked the three "warmest moons" occurring after the summer solstice. The first predawn appearance of Sirius, last of the three stars to rise, served as a warning for the people to leave the mountain, for soon the last moon before the start of winter would make its appearance. The concept of using a heliacal rising to announce a celestial event is one we see fully developed in Mesoamerica. The astronomical hypothesis for the medicine wheel is further strengthened by two additional facts: the alignment EO points to the position of sunrise at the summer solstice and the twenty-eight spokes of the wheel are equivalent to the number of visible moons in a lunar synodic month.

Though the Big Horn Medicine Wheel is the only one which has been subjected to a rigorous analysis, archaeologists are beginning to regard the orientation of the other wheels more seriously. Eddy and archaeological associate Thomas Kehoe have found that the Moose Mountain Medicine Wheel in southeastern Saskatchewan marks the

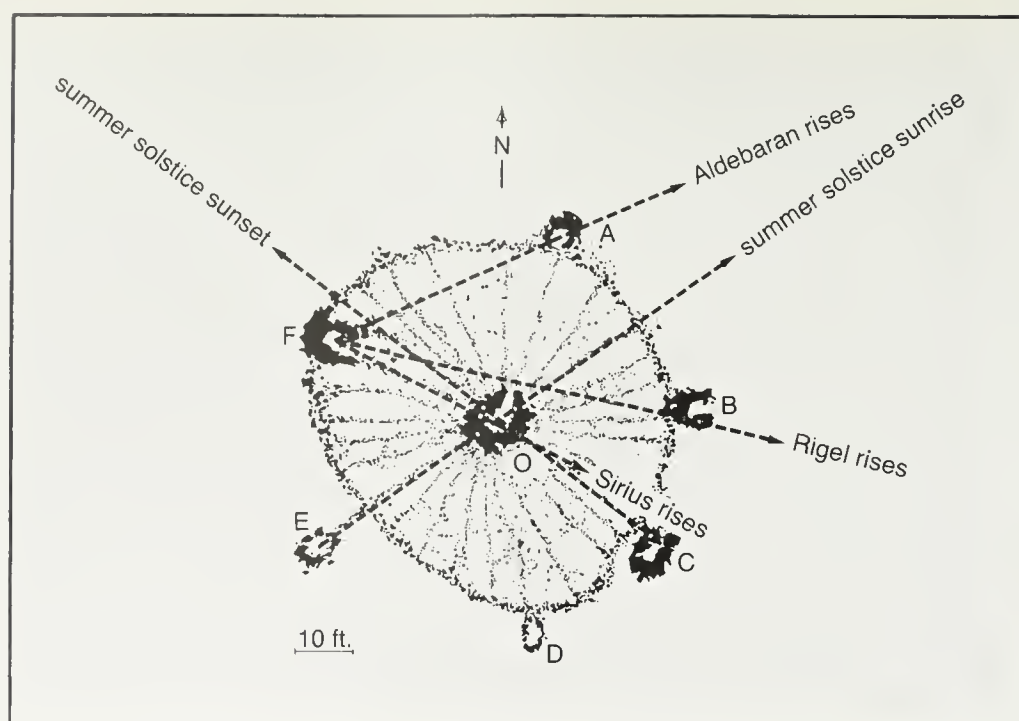


FIG. 106. Astronomical alignments at Big Horn. (Eddy, 1977, p. 152)

same astronomical events as does the Big Horn, while the Fort Smith, Montana, Medicine Wheel, though much smaller and containing fewer spokes, is also astronomically oriented. Its longest spoke points to the summer solstice sunrise point.

Critics of the astroarchaeological approach to medicine wheels have suggested that the primary and perhaps only function of the wheels was geometrical or that the wheels symbolized the mandala (a circular design symbolic of the universe). But the need to find a single explanation for every ancient artifact may be a product of our own Western method of reasoning. We have no basis to assume that the American Indian also would have sought a single principle. At the subconscious level the circular symbol of closure is also evident in the pecked-cross designs which, we can be sure, functioned in a multitude of ways. The geometrical explanation, which implies that cairn placement is derivable independent of any argument relating to astronomical alignments, may, in fact, strengthen the astronomical argument when we realize that the Native American mind was geared to a unification theme rather than a strict cause-effect view of nature. A medicine wheel which reflects both geometrical and astronomical as well as symbolic truths seems quite consistent with what we know about the pre-Columbian outlook.

The Indians of the Great Plains employed a different astronomical alignment scheme. They utilized paired earthen mounds, often quite distant from each other, to mark time in the solar cycle. Waldo Wedel (1967) of the Smithsonian Institution has investigated five so-called council circles in central Kansas for possible astronomical orientation. He finds that these arrangements, one of which is depicted in Fig. 107, still function as solstice registers today, the summer solstice being

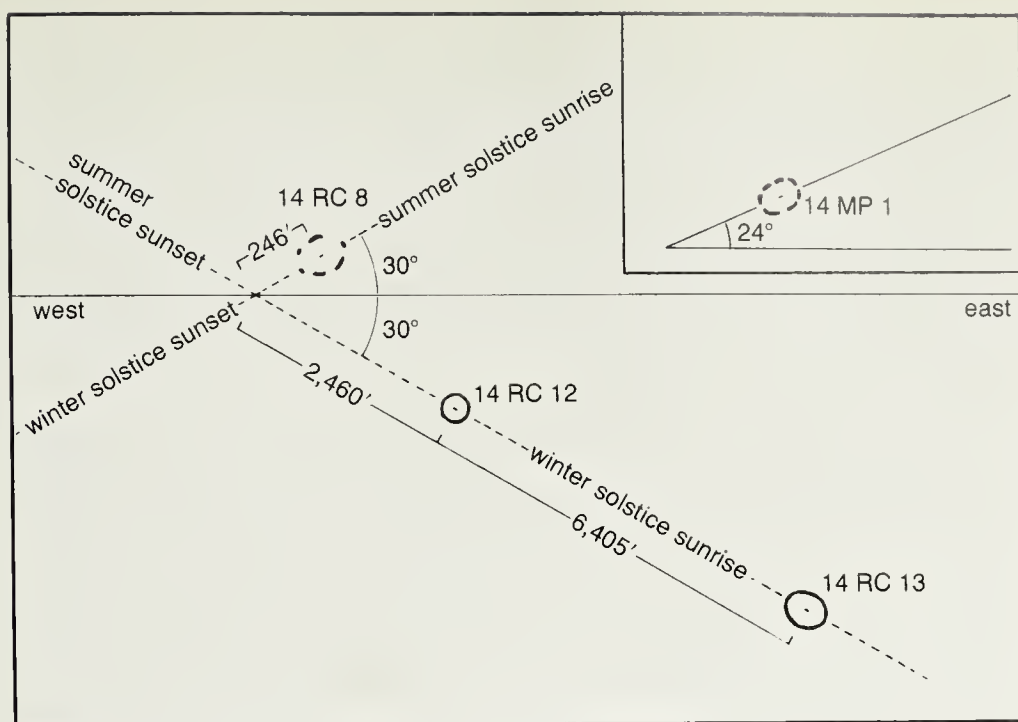


FIG. 107. One of the council circles of Kansas. (Wedel, 1977, p. 145)

marked most often. The Pawnee and Caddo people of this area were especially steeped in star lore. The Pawnee view of the cosmos is reflected in the plan of their earth lodges. The vaulted dome of the lodge represents the celestial sphere, and its circular plan imitates the horizon. Posts supporting the dome were implanted in the semicardinal directions, each symbolizing a directional star god; they were often painted in different colors, reflecting the habits of their Mesoamerican neighbors. The doorway to the lodge was so arranged that the rising sun at the equinox would illuminate an altar at the rear of the lodge. Sometimes the large-scale plan involving the arrangement of lodges on the landscape possesses an astronomical significance which may pass well beyond being purely symbolic. Alice Fletcher (1902), who queried Pawnee informants about the plan of their village at the turn of the century, reported that "there were five villages which formed a central group. The positions of these villages were fixed by the position of the stars which had given them their shrines and ceremonies. About this central group were located the other villages of the Skidi band, each in a position corresponding to that occupied by the star of its shrine so that the villages of the Skidi on the earth was a reflected picture of their stars in the heavens," (p. 734). Other outlying villages dot the map which accompanies her work. They seem to form a random pattern. A North Star village appears at the top of the diagram, but unfortunately no attempt was made to identify the other dozen villages with actual stars.

Elizabeth Benchley (1970), a University of Wisconsin anthropologist, has examined intermound alignments on maps of thirty-two Mississippi valley sites. She finds solstitial orientations at twenty-nine of them, with multiple orientations to the solstice at most sites. Though

no transit measurements were taken in connection with this project, her results are, nevertheless, statistically significant; they suggest that accurate field surveys should be carried out. The analysis reveals that the solstice orientation is the most common alignment employed, occurring with four times the frequency of equinoctial alignments.

Cahokia, a mound complex in the heart of the Mississippi valley near St. Louis, contains the largest earthworks in North America. Until recently, it also concealed evidence that its builders planned and organized the ceremonial center according to astronomical principles and that they were particularly concerned about registering the position of the sun at the equinoxes.

Excavating near Monk's Mound, largest of the structures at Cahokia, archaeologist Warren Wittry (1964) discovered a number of precisely spaced postholes arranged in circular patterns. Carbon dating revealed that the complex was erected about the tenth century A.D. Wittry calls the largest of these arrangements an "American Woodhenge," a variation on the term *henge*, which usually applies to the hanging stones, or lintels, found at Stonehenge. The pattern consists of forty-eight holes, probably intended to hold huge posts. Each posthole is exactly $7\frac{1}{2}^\circ$ from its adjacent companions as viewed from the center of the circle about 70 meters from the perimeter. An observer situated behind the backsight "observation post," which stood about 2 meters east of center, could have taken accurate sunrise lines from this eccentric position. The fourth posthole counted north or south of east could have been used as a foresight in this arrangement to indicate summer and winter solstice, respectively. An exact equinoctial line runs from the observation post to the easternmost hole. Wittry's plan of the Cahokia woodhenge is shown in Fig. 108. The remaining four holes between the solar extremes may have marked intervals in the solar year, while the others could have been involved in a calendric count.

Most of the one hundred Cahokia mounds are oriented on the cardinal directions; however, Pottery Mound, located 1,000 meters southeast of the center of the 15-acre complex, is skewed 30° off the east-west line, its axis aligning with the December solstice sunrise–June solstice sunset axis. Large elevated mounds mark the vertices of the diamond-shape plan enclosing the ruins at three of the four cardinal points. The north-south axis cuts through Monk's Mound, which also serves as the focal point of a geometrical arrangement of nearby mounds set out on corners of an equilateral triangle. A. Daniel, in a recent dissertation on southeastern United States (1979), has criticized Wittry's interpretations.

Astronomical mound alignments are also represented in the southeastern United States. The shell mounds of Crystal River near Tampa, Florida, have been found to be astronomically oriented by University of Florida archaeologist Clark Hardman (1971), who photographed a series of sunrise and sunset events at the site. He found that lines between pairs of mounds clearly were directed toward summer and winter solstice sunrise and sunset points. A pair of weatherbeaten stelae, the only ones known to exist in North America, suggest that the stela cult which flourished in southern Mexico probably diffused across the Gulf of Mexico about the fourth century A.D. Hardman's ex-

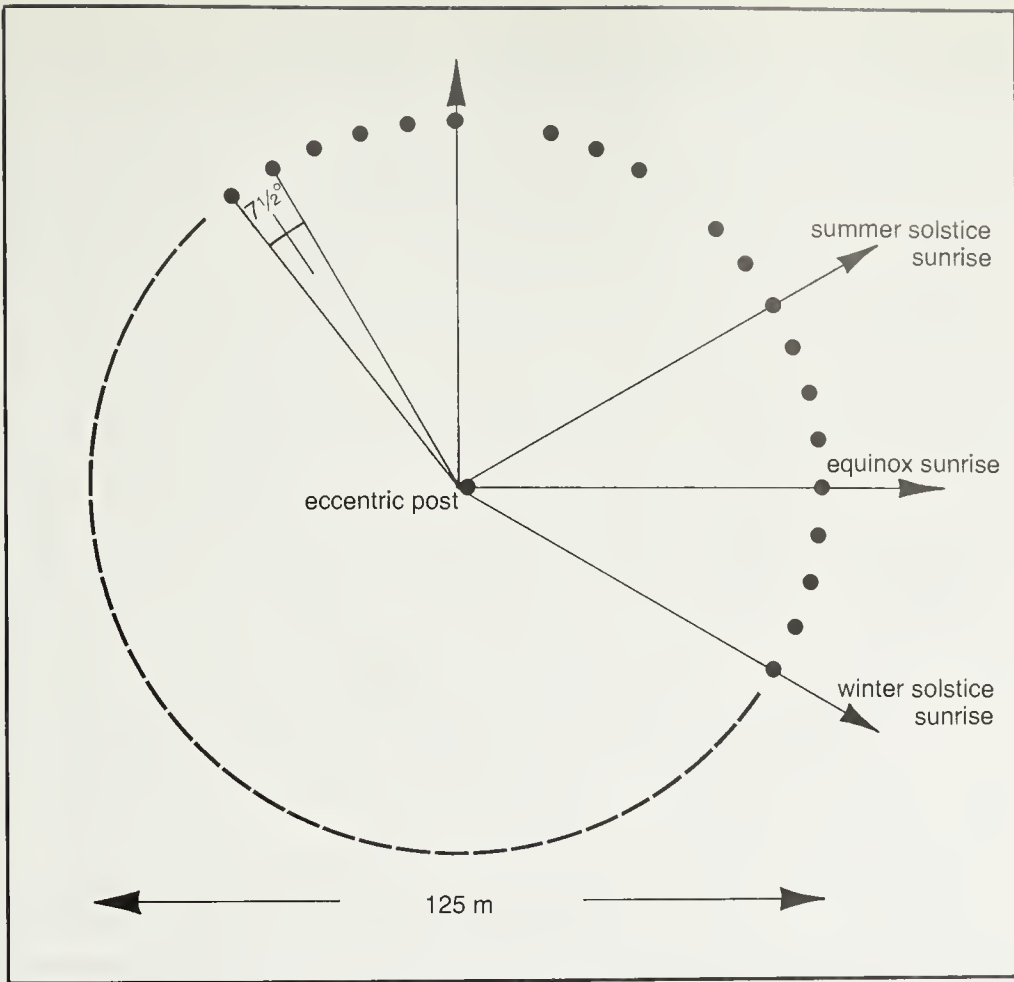


FIG. 108. An American Woodhenge. (Diagram by P. Dunham after Wittry, 1964, p. 102)

amination of the Gulf water currents for all seasons of the year revealed that a trans-Gulf migration was certainly possible and that the two most likely places for accidental contact were the Tampa Bay area of western Florida and the Louisiana coast just west of the Mississippi delta. Hardman also suggested that Moundville, Alabama, and Winter-ville, Mississippi, a pair of inland sites, showed significant solstice and equinoctial arrangements.

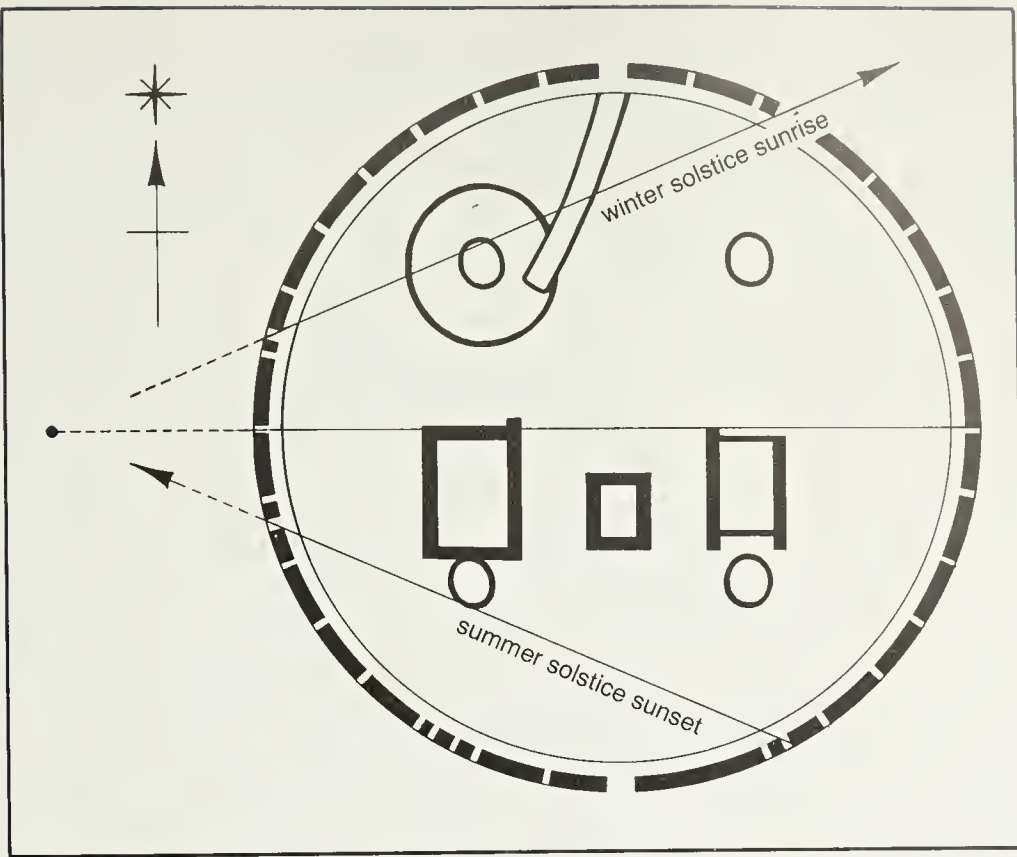
The largest mound at Poverty Point, Louisiana, is a vast octagonal earthwork over a kilometer in diameter, located up the Mississippi River near Vicksburg. It possesses an orientation suspiciously close to the unusual 8° west-of-north axi-ality of the principal Olmec ruin of La Venta. A secondary mound nearby is oriented exactly at right angles to this direction. Neither axis conforms to the symmetry displayed in the array of concentric octagonal ridges which are cut by aisles passing to the center. The geometry of Poverty Point remains as exquisite as it is mysterious.

Individual buildings possessing astronomical orientation also occur in North America. Perhaps the most well studied (and the most controversial) example is Sun Temple at Mesa Verde in Colorado. Situated atop a broad plateau, this D-shaped structure commands a sweep-

ing view of the horizon on all sides. It has been variously suggested that the flat-sided southern wall of the D is aligned to the equinoctial sun, the solstitial sun, several bright stars, and, finally, nothing at all. The matter still seems to be open to question (Reyman, 1977). Considering the more northerly latitudes associated with these sites, we might expect pole-centered astronomical systems to exhibit wider practice than we found in Mesoamerica. At Chaco Canyon, New Mexico, astronomer Ray Williamson and his associates (1975) find numerous kivas oriented precisely to the Pole Star (Fig. 109). Jonathan Reyman (1976), an anthropologist, discovered a less precise Pole Star orientation at Mesa Verde. He found a star pattern resembling the Little Dipper pecked into a ceiling above a window facing north at the Cliff Palace Ruin. It may have been common for ancient North American astronomers to record the celestial views they witnessed in a much less abstract way than the Maya, who employed rather complex constructs like the elaborate Lunar Series of hieroglyphs to record moon age and position. Petroglyphs representing complex constellation patterns have been reported in California (see, e.g., Mayer, 1977). Several possible depictions of the Crab Nebula supernova explosion of A.D. 1054 have been interpreted (Brandt et al., 1975; Brandt and Williamson, 1977). These show a bright star with the attendant thin crescent moon as they appeared together in the early morning sky on July 5, the day the "guest star" first flared to maximum brilliance.

Though the archaeological and ethnographic record concerning the practice of astronomy among Native North American people is relatively sparse, it suggests, as we might expect, that, judged by the usual standards, people who lived in what is now the continental United States were not nearly as advanced as their neighbors to the south. They possessed no system of writing or sophisticated notation to aid in the development of scientific astronomy. We can be sure that, while they manifested an intense interest in naming and mythologizing stars, the northerners exhibited little interest in the utilization of celestial cycles in complex schemes of prediction, such as those which fascinated the devout timekeepers of the Yucatán Peninsula (see discussion in Chapter IV). However, some attempt at exactitude is implied by the recent discovery of an Anasazi petroglyph that seems to have functioned as a time marker via a shadow-casting scheme (Sofaer et al., 1979). The abundance of solstitial alignments which show up north of the Mexican-U.S. border may reflect a concern about the association of the larger shifts of the sun's position along the horizon with the more pronounced seasonal extremes of climate as one moves away from the Tropic.

Interdisciplinary works like that of Hudson and Underhay (1978) on the Chumash have contributed to our understanding of the need for calendric systems among the Mesoamericans' neighbors to the north. If we think of pre-Columbian culture as a continuous and widespread phenomenon, we might expect further parallels. The people who built Big Horn Medicine Wheel and the Caddoan earth lodge conceived of the unit of space and time in the same general manner as those who designed the cross petroglyphs of Teotihuacán. The functional use of the Big Horn as a mechanism for defining specific spatial locations



a



b

FIG. 109. (a) Plan of Casa Rinconada, Chaco Canyon, showing astronomical alignments (diagram by P. Dunham). (b) View from ground level looking north; one of the solstice windows is visible to the right of center (courtesy of Ray A. Williamson).

along the astronomical horizon and the linkage of the observations to a time count reflect the highly integrated aspect of the realms of space and time so dominant in Mesoamerican cosmological thought. It may be especially significant that, beyond the expected common use of solstice and equinox sighting, we also find heliacal risings being used in Big Horn to mark calendric periods. It is especially noteworthy that Sirius and Aldebaran, two bright stars used for building orientation in Mexico, also appear in alignments far to the north.

The medicine wheel and additional alignment studies have added greatly to the popularity of and interest in the field of North American archaeoastronomy. At a meeting on archaeoastronomy in the Americas held at Santa Fe in June 1979, nineteen papers (43% of the total) addressed the subject. North American Indian astronomy seems to hold a particular fascination for the North American audience who now occupies the land once held by a race of people so long regarded as distant noble savages.

"The Incas had little knowledge of astronomy and natural philosophy since they had no letters." So writes sixteenth-century chronicler Garcilaso de la Vega, part Inca himself, in his *Royal Commentaries of the Inca* (1969, p. 114). These master masons had stormed the Cuzco valley, erected massive stone walls and temples, and developed an empire stretching over all of western South America on the eve of the Spanish conquest—and they did it all in less than a century. Actually, a rich cultural tradition dating back to Huari, Chimu, and Nazca serves as the base for the development of Incaic ideas about cosmology. It may be premature to dismiss ancient Andean astronomy as unimportant because that civilization exhibited no elaborate system of writing as we know it to preserve their calendar. They did keep a count of things on a unique device called a *quipu*.

As the sketch by one of the chroniclers shows (Fig. 110), the principal feature of a Peruvian *quipu* (which means "knot" in the native Quechua language) is a long cord from which a series of secondary cords branched out. Knots tied in the cords indicated numbers in a decimal system of numeration by position. The numbers that chronicler Felipe Poma de Ayala (1936) sketched in the lower left corner accompanying the figure of the *quipu* specialist were probably intended to indicate details of the counting procedure. They may not be very reliable since the artist neglected to draw any knots on the *quipu*.

L. L. Locke (1912), an early investigator, concluded that the *quipu* served two primary purposes: (a) to simply record numbers and (b) to aid in the memorization of historical and cultural tradition. For the Western traditionalist, it is difficult to imagine a notational system lacking a writing implement and tablet. Nevertheless, *quipu* were used to keep records.

E. Nordenskiöld (1925) claimed to have found numbers of astronomical and mathematical importance in the sixteen *quipu* he analyzed. He proposed that the Inca astronomer's notebook included a tally of the lunar synodic month; the tropical year; the synodic periods of the planets Venus, Mercury, and Jupiter; and certain prime numbers, especially those containing 7's (he mentions 17, 37, 337, and 677). It is difficult to know to what extent Nordenskiöld played with numbers to



FIG. 110. An Inca *quipu* expert. (Poma de Ayala, 1936)

arrive at his conclusions. A thorough compilation of all extant *quipu* data (more than 300 survived the conquest) has now been produced by R. and M. Ascher of Cornell University (1978). It is hoped that their corpus will provide the much needed material for comprehensive work on the subject.

There is little doubt that Andean people watched the heavens closely and were able to determine certain calendric intervals which resulted therefrom. Great halls in their Temple of the Sun, in the ward of Coricancha in Cuzco, were dedicated to the most important heavenly bodies—the sun, the moon, even Venus and the Pleiades, according to Garcilaso:

Another hall, next to that of the Moon, was dedicated to the planet Venus, the Seven Kids and all the other stars. The star Venus they called Chasca, meaning “having long curly hair.” They honored it saying that it was the Sun’s page, standing closest to him and sometimes preceding and sometimes following him. The Seven Kids they respected for their peculiar position and equality in size. They thought the stars were servants of the Moon and therefore gave them a hall next to that of their mistress, so that they would be on hand to serve her. They said that the stars accompanied the Moon in the sky, and not the Sun, because they are to be seen by night and not by day. (1969, p. 182)

Venus, the attendant to the sun, was recognized as the same body whether it appeared ahead of or behind the sun. Its heliacal rising and setting were observed. The planet was thought to have been ordered by

the sun to go sometimes before him (morning star) and sometimes behind (evening star) but always to remain close by.

Our measurements indicate that the temple itself possesses an astronomical orientation, the opposite inner halls looking out toward the June solstice sunrise and December solstice sunset positions on the Cuzco horizon. The principal streets in the environment of the temple also face these important directions.

A page from a manuscript (Fig. 111) produced shortly after the conquest, by chronicler Joan de Santa Cruz Pachacuti Yamqui (1951), attests to the importance of Incaic constellations and the central role of the Coricancha temple in astronomical endeavors. It also dramatizes their dualistic, vertical view of the cosmos, which still persists today (B. Isbell, 1978). The temple, located in the center of the capital of the Inca empire, is shown in a lateral view, divided into solar (*left*) and lunar (*right*) houses. Venus as morning star is clearly labeled "Chasca" (= "shaggy hair"), and the Pleiades and the Southern Cross are among the constellations represented (others are marked in the figure). The former is labeled the "stars of summer," probably because in the latitude of Cuzco the Pleiades make the first appearance after sunset in the eastern sky shortly before the arrival of the December (summer) solstice in Cuzco. Thirteen Pleiades stars are shown, not an unrealistic number to be observed in the thin Andean air. Below we also see them represented as the seven eyes of the God of Thunder, Viracocha. The Southern Cross, called the "hearth" (with a fifth star added in the right place!), appears at the center of the diagram below the oval Coricancha altar. Another version of the Southern Cross has been suggested as representing the group of stars near the rooftop of the Coricancha (or is it a Christian Cross?) with its axis pointing directly to the apex of the roof of the building, which represents the South Pole. As the map in Fig. 22*b* shows, it points to within 5° of the pole. An alternate representation of the rooftop constellation is found in Orion, the three belt stars in the middle with bright Betelgeuse and Rigel forming the top and bottom extensions of the cross. Curiously, an unmistakable Orion configuration is pictured at the left edge of the page outside the Coricancha. The region of the Great Nebula in Orion is circled in precisely the correct place to support this identification. A possible dark cloud constellation (*chuqui chinchay*) appears at the right of the diagram.

Analyzed in a purely symbolic way, the Pachacuti diagram may be divided horizontally into three layers: the heavens (*top*), the real world (*center*), and the underworld (*bottom*). Cleaved vertically, the left side of the ledger is masculine, while the right side pertains to phenomena of a feminine nature. The cosmic cat symbolizes "*pacha mama*," or earth mother, the time in August when the earth opens up and it is time to sow seed. This is also the time when the sun passes directly opposite the zenith at midnight. The lightning flash, or "*rayo*," is the beam of the sun. It descends from above at the time of the passage of the sun in the zenith. Rituals are still celebrated at these important times in the calendar (B. Isbell, 1978). The dualism of verticality is reflected in the design of ancient Cuzco, which incorporates an astronomic sight line connecting the place of appearance of sunrise on the day of passage across the zenith with the point of "antizenith" sunset (Aveni, 1979*a*; Zuidema, 1979).

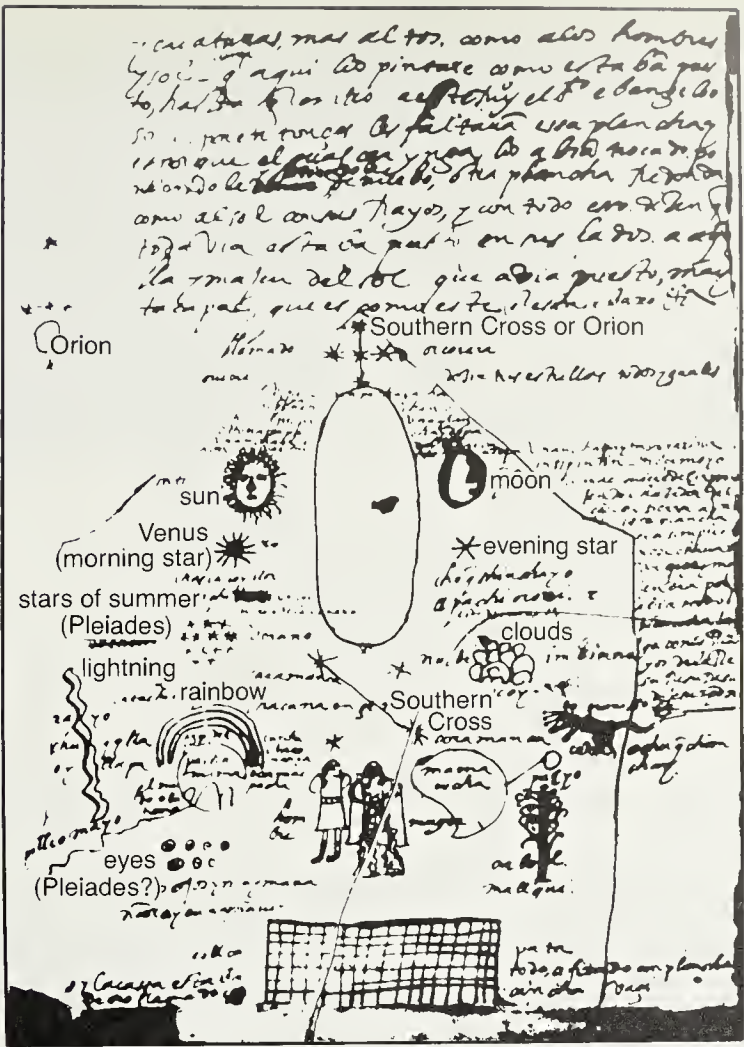


FIG. 111. Astronomical objects of importance to the Inca. (Santa Cruz Pachacuti Yamqui, 1951)

Studies by anthropologist Gary Urton (1981) indicate that modern Andean people take the Pleiades and the tail of Scorpio to represent two opposing groups of stars, which they employed in the ordering of terrestrial space. Rising and setting in opposition, they are connected by an axis in the plane of the horizon which passes through the local village. The appearance and disappearance events associated with these star groups are used to set up the local agricultural calendar. Urton suggests that (there is thought to be a real cause-effect connection between the Pleiades apparition and the crop yield, for the people say that if the cluster is large and bright when it first rises the crop and harvest will be successful, whereas if it is small and dim the prognostication is negative.) The Milky Way, so prominent in the Southern Hemisphere, and especially dazzling from the rarefied atmosphere of the Andes, is central to Quechua cosmology. It is "Mayu," the celestial river, a continuation of the vital river system which flows through the Valley of Cuzco, branching out to its remotest parts via a complex array of aqueducts.

According to Urton, the modern Quechua see black constellations when they look at the dark obscuring clouds of the southern Milky



FIG. 112. Inca masons—builders of the *mojones*. (Poma de Ayala, 1936)

Way. Among these are Yutu, the partridge (represented by the Coalsack region); Machacuay, the snake (in the dark region between Canis Major and the Southern Cross); and a llama made up of interstellar matter between the Southern Cross and Epsilon of Scorpio—Alpha and Beta of Centaurus, two bright jewels of the southern sky, marked the llama's eyes. Some of these zooform constellations whose appearance he correlated with their life cycles are exhibited in Fig. 15.

What the Maya did at Copán, the Inca also accomplished at Cuzco. There is considerable historical evidence that the Inca utilized astronomical alignments to demarcate agricultural cycles in the Valley of Cuzco. A system of *mojones*, or pillars (Fig. 112), strung out along the horizon of Cuzco served as foresights to mark the solar positions, while an observer backsighted the events from somewhere in the center of the city. Because the Spaniards tore them down to build aqueducts for their new city, none of the towers remains today. The record stated in the postconquest chronicles, though filled with information, is somewhat confusing regarding both the number of pillars and the location of the observer's station; in fact, we can now be certain that there was more than one observation point.

An anonymous chronicler tells us that four pillars were built on a hill overlooking Cuzco from the west; the inner and outer ones were separated by 200 paces, while the two middle ones were 50 paces apart. "When the sun passed the first pillar this began the time when they were warned about the planting of vegetables at the highest altitude. When the sun entered the space between the two pillars in the middle it became the general time to plant in Cuzco, always the month of August. And when the sun stood fitting between the 2 inner pillars they had another pillar in the middle of the plaza . . . called the Ushnu, from

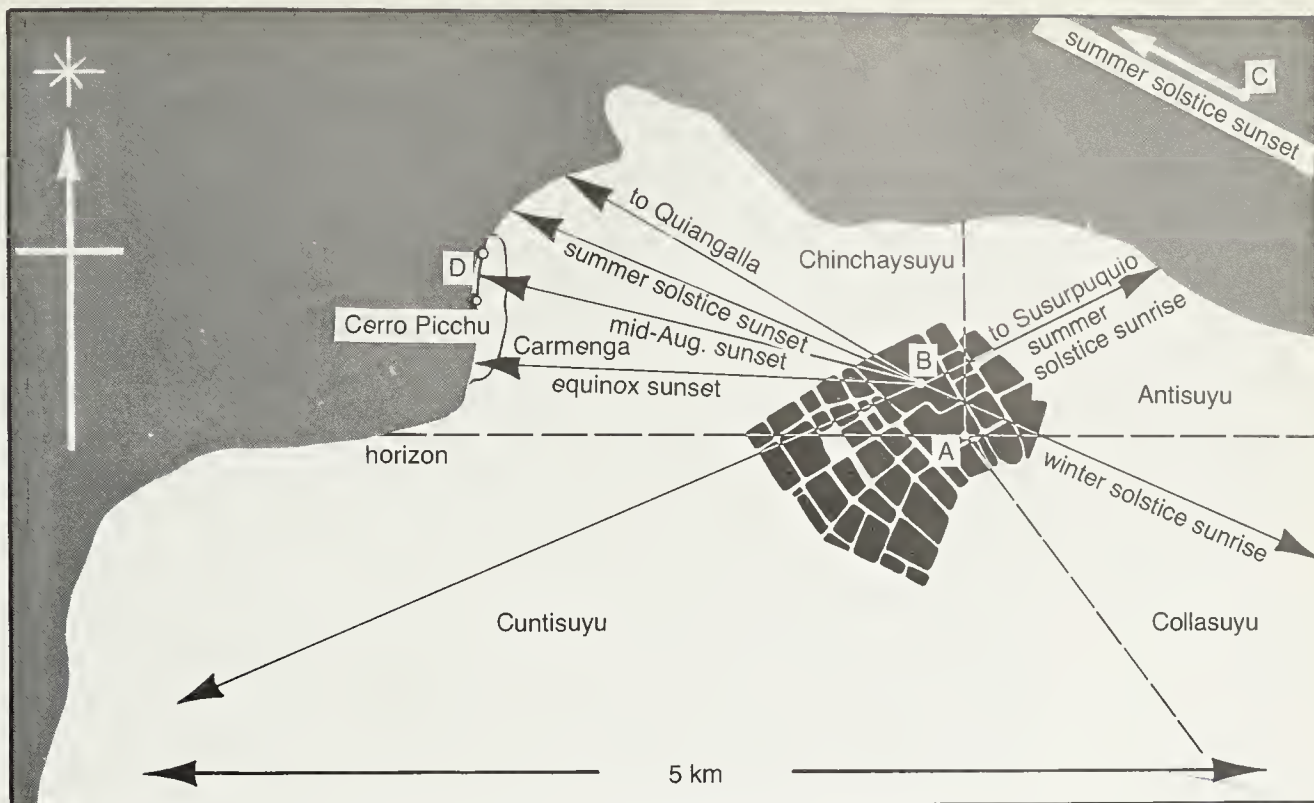


FIG. 113. Schematic plan of Cuzco; the dashed lines that divided the city into quadrants radiate from the Coricancha; sighting pillars and astronomical sight lines (solid lines) are indicated; the Cuzco horizon appears about the periphery of the city as the boundary between light and dark: (A) Coricancha, center of the *ceque* system; (B) The Ushnu, an astronomical observing station; (C) Lacco, a station used for observing June solstice events, located on a hill overlooking Cuzco from the north; (D) supposed location of pillars (*sucanca*) to signal the planting season. (Diagram by P. Dunham)

which they viewed it. This was the general time to plant in the valleys adjoining Cuzco" (Maurtua, n.d., p. 161; I am indebted to Stephen Fabian for an exact translation of all the passages cited from the Inca chronicles).

The hill to the west must be Cerro Picchu (Fig. 113), whose summit is but 2 kilometers from the present town square where the Ushnu was located. (A cathedral now overlooks the site.) The antizenith sunset (August 18 in the latitude of Cuzco) occurs on a precipitous down-slope just north of the summit. At the supposed distance from the site of the cathedral, the inner pillars would frame 1° of the horizon (two solar diameters), while the "200 paces" from the first to the last pillar translates to 4° of angular separation. About fifteen days would be required for sunsets to migrate across the zone marked by the pillars, providing a reasonable delay interval for planting at different altitudes in the vicinity of Cuzco. Three other sixteenth-century chroniclers—Pedro Cieza de León, Juan de Betanzos, and Pedro Sarmiento de Gamboa—confirm the essentials of the argument but disagree over details. Cieza (1973) locates the pillars on the mountain above Carmenga, the correct location, and describes the markers as "small towers." Betanzos (1968) calls the markers "pyramids" and places them rather close to-

gether; nevertheless, he specifically states that they were used to indicate the time to plant and, furthermore, that more than one observation of the sunset was involved. Sarmiento (1942) implies that both planting and harvesting were regulated and that the four "posts" were equally spaced. The pillar scheme, as objectively as it can be reconstructed from the available information, is sketched in Fig. 114a.¹⁵

Garcilaso also suggests that the pillars, which he saw still standing in 1560, were arranged in groups of four; however, he implies that more than one set was erected and that they were used to mark the solstices: "The space between the small towers by which the Sun passed in rising and setting was the point of the solstices. The towers to the east corresponded with those of the west, according to whether it was the summer or winter solstice" (1966, p. 116). Later he states that their primary purpose was astrological. Sarmiento also mentions four eastern pillars and Betanzos indicates that sunrise as well as sunset measurements were performed.

We should not be surprised to read conflicting reports about the number, nature, and location of these pillars among the several post-conquest historians who wrote about them. None of these men was known to be well endowed with a knowledge of positional astronomy, nor would anyone of Spanish origin writing at the time be too quick to credit his newly acquired pagan subjects with a knowledge of matters so esoteric as astronomy and calendar. Such pursuits would be totally at odds with the inferior view of the aborigines prepossessed by the invaders, who initially were interested only in the acquisition of the material wealth this strange land could provide. The extreme cultural bias of the New World scholars is expressed very well at the end of one of Fray Diego Durán's discourses on the Aztec calendar. After recounting the scheme the Aztecs used to lay out their months and years (with too little attention to detail), he states the rationale for his work:

Thus we terminate our brief and condensed version of the calendar. I understand, I realize, that I could have enlarged the book and described more things in a detailed way, but my sole intention has been to give advice to my fellow men and to our priests regarding the necessity of destroying the heathen customs which they will encounter constantly, once they have received my warning. My desire is that no heathen way be concealed, hidden, because the wound would grow, rot and fester, with our feigned ignorance. Paganism must be torn up by the roots from the hearts of these frail people! (1971, p. 470)

Still, the melange of tantalizing written fragments on the Incaic pillars enables us to draw a few more conclusions. As the map of the Cuzco horizon in Fig. 113 suggests, observations of both the June solstice sunrise and sunset easily could be taken on the nearby hills enveloping Cuzco on the north. But the southern horizon falls away from Cuzco very rapidly; for example, the point of December solstice sunrise is more than 20 kilometers from Cuzco. At this distance a pair of pillars of extraordinary dimensions and spacing inconsistent with that written in the chronicles would be required to frame the disk of the

sun. The facts obtained by surveying the southerly environs of Cuzco suggest that observations such as those indicated in the chronicles simply could not have been made in that direction.

The Inca, as did most ancient people, possessed an interest in timing the swing positions of the sun. Given the difficulty of determining the exact date of the solstice from horizon observations (see Chapter III), it would have been reasonable for Southern Hemisphere astronomers to devise a configuration of multiple alignments to mark the slowing of the sun as it reached its June (winter) limit.

A few of the chroniclers suggest that the Inca utilized another system of landscape timekeeping in which they made use of the gnomon. Cieza (1973, p. 214) refers to the observation place from which the Inca observed the sunset over the hill of Carmenga as a location, "where the Inca erected a flat plaza of mortar and stone to make solar observations." Is this the Ushnu of the anonymous chronicler? He fails to elaborate, though he seems to be talking about a place near the Hanan-Haucaypata, or present Plaza de Armas. But Sarmiento, after describing the horizon pillars, continues with this curious statement: "... he [Inca Tupac Yupanqui] put columns of stone in place and ordered the ground paved. On the flagstone he layed out graded rays to correspond to the direction of the sun as it entered through holes (in the columns), so that the whole device functioned as an annual clock. And there were certain people who kept the count on these clocks and accordingly notified the pueblo of the different times for planting and harvesting" (1942, p. 175).

Garcilaso describes a precise system (in a different location) when he tells how the timing of the equinox festival, Citua Raimi, was determined. (Note that he confuses the equinox date with that of the passage of the sun across the zenith.)

To ascertain the time of the equinoxes they had splendidly carved stone columns erected in the squares or courtyards before the temples of the Sun. When the priests felt that the equinox was approaching, they took careful daily observations of the shadows cast by the columns. The columns stood in the middle of great rings filling the whole extent of the squares or spaces. Across the middle of a ring a line was drawn from east to west by a cord, the two ends being established by long experience. They could follow the approach of the equinox by the shadow the column cast on this line, and when the shadow fell exactly along the line from sunrise and at midday the sun bathed all sides of the column and cast no shadow at all, they knew that that day was the equinox. They then decked the columns with all the flowers and aromatic herbs they could find, and placed the throne of the Sun on it, saying that on that day the Sun was seated on the column in all his full light. (1966, p. 117)

Were the chroniclers infusing their own knowledge of the sundial of the Classical World into the Inca system of horizon alignments? In the absence of any further statements about the sun device, we cannot judge for certain; but, given these specific statements about the carved

grooves and cast shadows together with the earlier ones about towers on the horizon, it appears that the Spanish chroniclers are talking about two different systems. Indeed, the Incaic system of timekeeping may have been more elaborate than we had hitherto realized.

Cuzco was built to conform to an elaborate plan which was intimately tied to concepts of Inca sociopolitical organization. P. Bernabe Cobo, in his *Historia del Nuevo Mundo* (1956), states that sacred shrines called *huacas*, 328 of them in all, were scattered in and about the city. Cobo's definition of a *huaca* leaves little doubt that he was talking about definite places in the environment: "On each one of those ceques were by their order the huacas and shrines that were in Cuzco and its region, like stations of pious places whose veneration was general to all; and each ceque was in charge of the factions and families of the said city of Cuzco, from which went out the ministers and servants that cared for the huacas of their ceque and waited to offer at their times the established sacrifices" (p. 169). Many of these *huacas* were positioned along straight lines, or *ceques* (called *raya* in Spanish; ray, line, boundary in Quechua), up to 15 kilometers long. Most of the forty-one *ceques* emanated from the centrally located Temple of the Sun (today the church of Santo Domingo); no two *ceque* lines ever crossed each other. While they served the primary purpose of dividing the city, according to R. T. Zuidema, an Andean scholar studying Inca social and religious systems, there are reasons to believe that some of the *ceques* also may have possessed an astronomical function. Zuidema's landmark studies of the *ceque* system (1964, 1977) have opened the door to further astronomical studies.

To begin with, the spatial domain of Cuzco is divided by an east-west line into an upper (northern) and lower (southern) moiety, each of which was halved to produce four quarters, or *suyu*. The *suyu* possess an ordered number of *ceque* lines (usually arranged in groups of three). Each *huaca* of a given *ceque* was worshipped on its own day, while the *ceques* and groups of *ceques* may have been connected with larger divisions of time (the number 328 can be taken to represent twelve sidereal lunar months).

Certain of these *huacas* seem to be related to the horizon pillars discussed earlier. They lie on specific *ceque* lines, as Cobo (1956) tells us:

(a) Ceque No. 6 of Chinchaysuyu (NW quarter) has eleven *huacas*, the ninth of which, counting radially outward from Coricancha, is named Quiangalla, "which is on the road to Yucay, where there stand two *mojones*, or pillars, which serve to signal the beginning of summer when the sun arrives there" (p. 172).

(b) The seventh *huaca* of Ceque No. 8 in the same *suyu*, the aqueduct of Chinchero, "had two pillars to signal when the sun arrived; this indicated the commencement of the sowing of maize" (p. 173).

(c) The Antisuyu (NE) quarter possessed 9 *ceques* and 78 *huacas*. The *huaca* Chuquimarca consisted of "a temple of the Sun on the hill of Mantocalla where the sun slept much of the time" (p. 176). Not only is this an obvious reference to the solstice, but also the *huaca* lies at the solstice point from Cuzco.

(d) The third *huaca* of the thirteenth *ceque*, Cuntisuyu (the SW

quarter), is called Chinchincalla. "It is a great hill where there are situated two pillars and when the sun arrives there it is time to sow" (p. 185).

The astronomical reference here seems to be the December solstice sunset, where, we noted earlier, the horizon is rather distant for the type of observation implied. Some of the astronomically related *ceque* lines are illustrated in the map of Fig. 113.

These references in the chronicles raise fundamental questions. Where were the observations made from and did a single point serve as the foresight? Though *ceques* emanated from the Coricancha, we are told by more than one chronicler that some of the *mojones* were viewed from the Ushnu in the present Plaza de Armas, about 500 meters northwest of the Temple of the Sun. Not only could both locations have been employed, but also a third observatory seems to be implied, because the June solstice sun viewed from the Ushnu sets in the valley to the south of Quiangalla, where Cobo says it was positioned (from the Coricancha it lies still farther south). A place called Lacco on a hill north of the city is a logical location for the third observatory because the sun temple called Chuquimarca was located there; furthermore, only a station in that vicinity fits the astronomical requirement given in statement (a).

A number of rock outcrops that were carved with niches, windows, passages, and interior altars, including Lacco, can be found in the environment of Cuzco; the directions of many of these artificial features seem to have general calendrical and astronomical significance. Often they are specially arranged so that the sun shines directly upon them. Employing ethnohistoric evidence, astronomical arguments, and architectural and topographic data gathered through appropriate instrumentation in the Cuzco environment, Zuidema (1979) and I (1979a) have established beyond doubt the existence of three astronomical sighting directions which emanate from three different points in the Cuzco area:

- (a) A pair of pillars which mark the June solstice sunset point as viewed from Lacco, a complex of rock carvings on a hill north of Cuzco.
- (b) A pair of pillars to mark the December solstices as seen from Coricancha, the center of the *ceque* system.
- (c) The *sucanca*, four pillars situated on Cerro Picchu to mark time for the planting season, centered on the place where the sun sets on the day of passage through the antizenith (Fig. 114a).

The last line could be traced only when *huacas* of the *ceque* system could be located in the field. For example, Cobo tells us that *ceque* 8, radiating from the Temple of the Sun, passes over the hill of Carmenga, terminating at Sicllabamba. Different *huacas* on that *ceque* can be pinpointed exactly (see Fig. 114b) because today half of them can still be located and many still retain their old names. Urcoscalla was a place "where those who travel to Chinchaysuyu lose sight of Cuzco" (Cobo, 1956, pp. 173–174). Based upon sightings of Cuzco made from the hills west of Cerro Picchu, we equate the place where the city disappears from view with a place bearing the modern name of Arco Punco (also

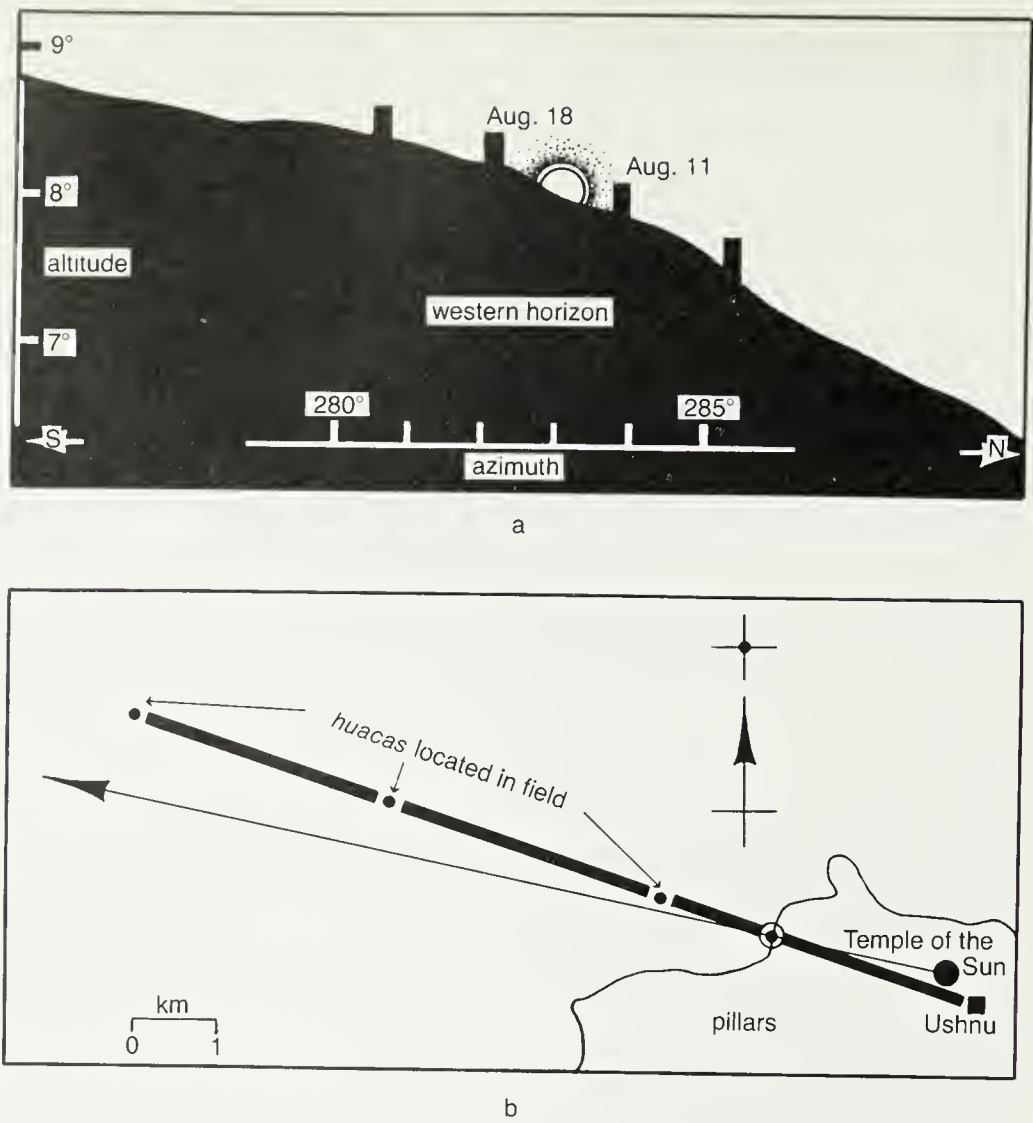


FIG. 114. (a) The position of the *sucanca*; (b) the crossing of a *ceque* line with an astronomical sight line illustrates how ethnohistorical evidence can aid in the derivation of an astronomical alignment. (Diagrams by P. Dunham)

included on the map). Radially outward from the Coricancha along the same *ceque* (*huaca* 12), we find Poroypuquio ("the well of Poroy"). Cobo says that the Spanish built a watermill there; the ruins of the mill can still be seen near the village of Poroy. Collanasayba ("the principal *mojon*"), located 13 kilometers radially outward from the Temple of the Sun, is a rock outcrop about an acre in area located at a prominent bend in the river coming from Poroy. Original Inca walls had been found when the modern road to Chinchero was constructed and the hacienda there still bears the original name. The hill is also called Collanasayba. Now, Collanasayba belonged to Sicllabamba, a name still given to a former hacienda. The house of that hacienda still stands adjacent to this, the last *huaca* of its *ceque*. The place must have been ideal for the ritual purpose of throwing offerings brought from Cuzco into a river at the end of a *ceque*, a practice referred to often by the chroniclers.

Using the surveyor's transit, we traced the *ceque* as a straight line

(the heavy line in Fig. 114*b*) over the mountains between Collanasayba and the Coricancha in Cuzco. The goal of this exercise was to approximate the position on Cerro Picchu where the straight line would cross (Fig. 114*b* shows the spot). Since the *sucanca* lay on the *ceque* line but were astronomically observed from the Ushnu, we saw a means of fixing the important sunset line and corresponding date in the agricultural calendar and locating the site of the Ushnu (known to have been somewhere in the Hanan-Haucaypata, or the present Plaza de Armas), as well.

The position of the Picchu *sucanca* thus having been located (we erected our own *sucanca* on the spot by piling up stones), we set up the transit there and shot a series of lines into the Plaza de Armas, seeking to determine for what dates sunset could be viewed over the *sucanca* from various points in the plaza. One line to which we paid particular attention (the light line in Fig. 114*b*) was the antizenith (August 18) sunset date. As we have seen, the importance of the passage of the sun through the zenith is mentioned frequently in the chronicles (see, e.g., Garcilaso de la Vega, 1969). A zenith-antizenith alignment in Cuzco would accord very well with the verticality symbolism so prominent in Andean thought and with statements made by Guaman Poma (1936, ff. 883–884) that the earth opens up in February and August, the zenith-antizenith sun dates. On the antizenith sunset day, the sun disappears over the western horizon at a point about 180° opposite the sunrise point on the day of zenith passage. (Actual differential horizon elevations cause the line to deviate by as much as 1/2° from linearity, but the azimuth is, nevertheless, about 283°.)

By a fortunate circumstance, our assumptions and calculations were further abetted in the summer of 1978 by the results of Zuidema's examination of a 1653 painting by artist Estrada Monroy (Fig. 115), located in the cathedral of Cuzco. In it we see the city in the aftermath of the earthquake of March 31, 1651, barely a century after the conquest. The view is from the top of the cathedral looking toward the southwest, the same as the orientation of the map. Near the center of the picture (enlarged in the detail) we see a vertical column supporting a cross. This is the *rollo* (or *picota*) which Pizarro was said to have placed on the site of the Ushnu shortly after he conquered the city (Betanzos, 1968, p. 70).

The Ushnu itself is a very elusive concept. Its relation to verticality in the Inca cosmos is fully developed in Zuidema (1977 and 1979) where we find it manifested in a multitude of material objects, including an altar of sacrifice, a platform of stones, a *mojon*, and even a hole in the earth.

We note that if we join the Plaza de Armas (the old Hanan-Haucaypata) with the Plaza de Regocijo (the old Cusipata) to the southwest to form a single plaza, the stone would have lain near the center. We note further that the Ushnu is situated comfortably within the August 18 viewing band calculated from our measurements of the *ceque* line containing the *sucanca* on Picchu. Archaeologists should be encouraged to begin exploration at the predicted Ushnu site as well as the site of the pillars.

We have seen that the record given in the Inca chronicles is often

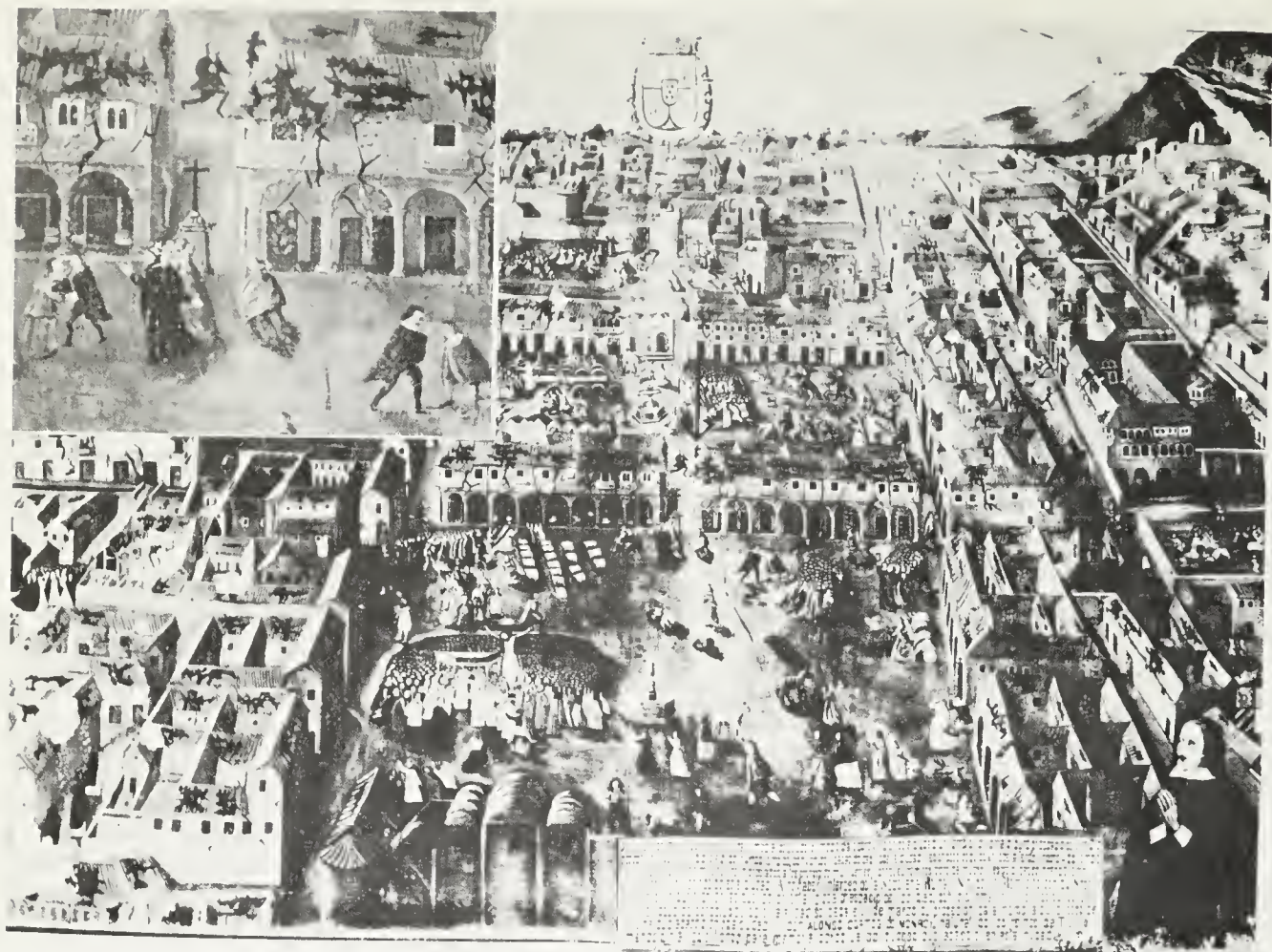


FIG. 115. This painting of the great Cuzco earthquake provides an important clue to the location of the Ushnu (arrow; enlarged in detail).

confused and that the commentary reflects the ever-present Western philosophical bias about the low level of cosmological thought the Inca were believed to possess. Sarmiento and Cieza, like Durán and Sahagún in Mexico, seem to have turned a deaf ear to their informants when it came to astronomical matters. But we have also learned that, while the record on Inca astronomical practice is incomplete and much work still needs to be done, already there is little doubt that the world views of the Inca and of the people of Mesoamerica were similar. The concept of time flowing around the direction of the horizon is reminiscent of the use of the temporally related cardinal directions among the Mexicans, especially as it is manifested in their calendar wheels. The division of the Inca calendar and the quadripartite segmentation of their capital parallels a cosmological view shared by many preliterate civilizations of the world. Anthropologists shall ever debate whether a universal view of the natural order composed of archetypes was built into our minds long before we became civilized. Or do the similarities we find among different and distant cultures result from the diffusion of ideas among them? Or neither?

Geographer Paul Kosok (1965) called the desert plateaus of coastal Nazca, Peru, the "largest astronomy book in the world." The mammoth markings scratched there are no better understood now than

they were in 1941 when Kosok brought their startling discovery to light through aerial photography (Fig. 116). Practically invisible from ground level, long thin rectangles, trapezoids, and skinny triangles, some running tens of kilometers, reveal a mazelike pattern over a thousand square kilometers of abandoned wasteland when viewed from the air. The geometrical shapes are accompanied by animal figures, up to a kilometer long. Many of the creatures are birds, but there also occur a spider, a fish, a serpent, a monkey, a dog, and several deformed men—over one hundred figures altogether, traced out by artists who removed the dark coarse layer of topsoil, exposing a lighter-colored desert sand a few centimeters below. These ancient sand painters accomplished their art with their feet or, perhaps, a broom as they walked off a given pattern. Low rainfall and a generally calm meteorological environment have enabled the delicate tracings to persist for more than a thousand years.

Mathematician Maria Reiche (1949), who became interested in the desert drawings through her affiliation with Kosok, cleaned, photographed, and carefully surveyed many of the figures. She has since lived in their environment for more than three decades. Reiche has been very cautious about drawing conclusions regarding their nature until all the data have been assembled. She and Kosok, who studied the problem together a short while before his premature death, discovered some order in the apparently chaotic arrangement which confronts the eye of even the casual observer:

1. Many lines radiate from a limited number of centers, often located on small hills. Some of these centers contain the ruins of small stone monuments. Triangles and trapezoids often terminate in stone heaps at one or both ends (see Fig. 116a).

2. Single lines, which form a minority of the markings, are those which correlate best with astronomical positions. But zig-zag lines can also be seen running back and forth, as if to lead to nowhere. One zig-zags to and fro five times over a distance of 4 kilometers.

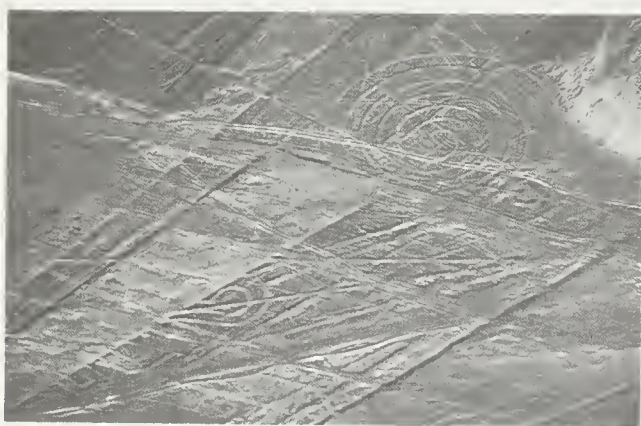
3. Most of the lines are double. They appear as roads, often climbing obliquely straight up and over the tops of mountains. Because of the corrections due to elevation discussed in Chapter III, Appendix B, we would expect horizontal astronomical sight lines to bend in the azimuth direction as they climbed and descended hills. This is precisely what the lines do in many cases.

4. The drawings of animals often are linked with designs, especially spirals. Reiche speculates that one double spiral (Fig. 116c) was drawn by sand painters who were guided by ropes wound about three vertical posts placed near the center. The exactitude with which this spiral and other figures are executed demonstrates the meticulous nature of Nazca earth geometry. Accordingly, a number of speculations about the use of a standard unit of length have appeared in the literature. Though it is likely that a standardized metric was employed, no thorough study has yet been undertaken to determine its length.

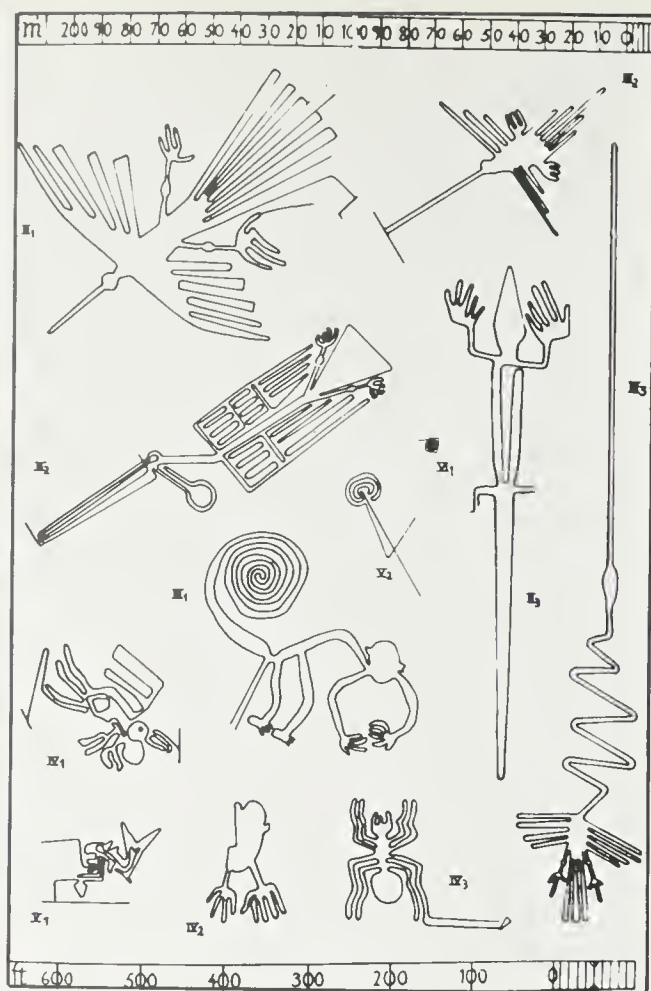
As W. Isbell (1978) has demonstrated, many of the designs resemble patterns found on Nazca pottery. For example, the killer whale shown on the desert floor in Fig. 116e also makes his appearance on the pot in Fig. 116f. Most of the desert figures were executed with a single continuous line which began on one side of the figure, traced out the



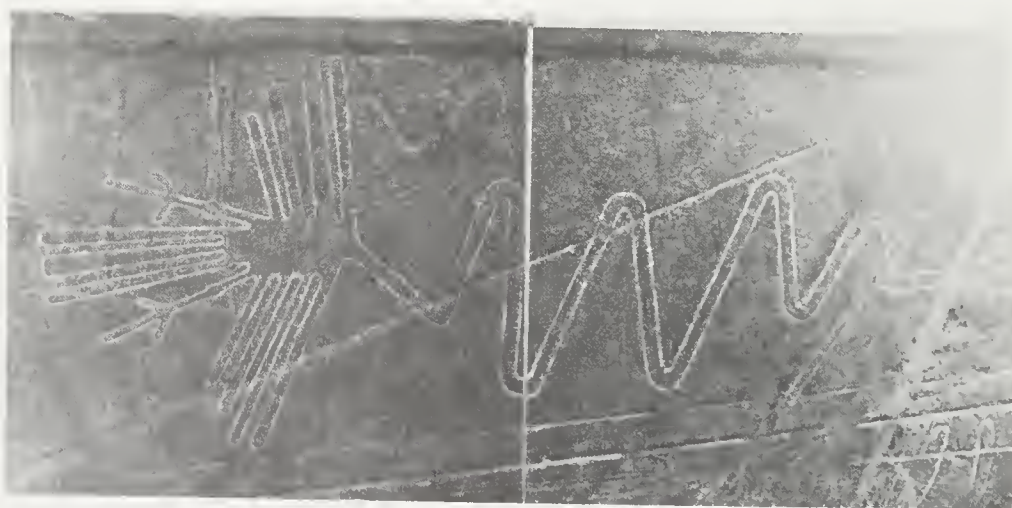
a



c

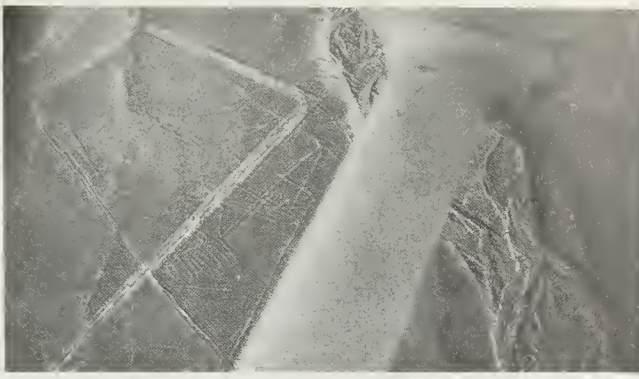


b

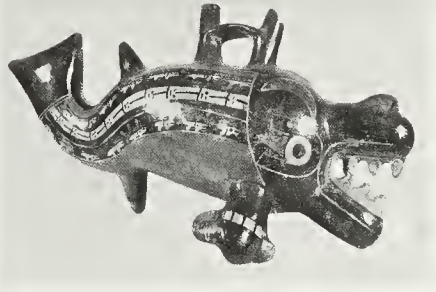


d

FIG. 116. Giant figures on the Nazca plain: (a) aerial photograph showing numerous triangles and lineations; (b) a selection of animals (Reiche, 1969, p. 53); (c) an exquisite spiral; (d) a bird with a long snakelike neck is discernible among the numerous lineations—one of the largest Nazca figures, it measures 100 meters from beak to tail feathers; (e) a killer whale appears just above the wing support of the aircraft; (f) the same design on Nazca pottery (photograph by Wilfredo Loayra L.; courtesy of William H. Isbell).



e



f

entire perimeter, and often ended where it began; all the figures reproduced in Fig. 116*b* serve as examples. It would have taken one person a continuous lifetime of work to produce all the figures we see on the desert floor today.

By sheer accident, Kosok was led to propose an astronomical hypothesis for the origin of many of the lineations. If it holds, then we must be prepared to believe that the Nazca culture, which preceded the Inca by more than half a millennium, must have developed a respectable calendar. While engaged in the cleaning and surveying of the first of the long rectangles he found, Kosok noted that the sunset occurred almost exactly along the direction of the figure—it was June 22, the winter solstice south of the equator (1965). A further examination led to additional astronomical correlations; for example, the bird with the long neck (Fig. 116*d*) points to a solstitial position on the horizon (sunrise at winter solstice). Later, Reiche discovered that two other animal figures point to summer solstice sunrise and sunset, as do several of the lines. She also discovered that portions of the zig-zag “oscillating” lines are solstice related. Finally, the largest rectangle points to the rising position of the Pleiades about A.D. 600, a date which fits the time of construction of the lines from the dating of pottery sherds. Some of Reiche’s lines point to bright stars, Castor and Antares among them; others, to the lunar extremes. Are we again witnessing the remains of a functional system of horizon-based astronomy as we found in Mesoamerica and as also developed among the megalithic cultures of north-western Europe?

Reiche believes unquestionably that a religious and ceremonial significance must have been attached to the Nazca lines. A ritual procession could have followed the tracing of the continuous line figures; also, the crossings of triangles and trapezoids may represent kinship

patterns. Reiche's years of working on the tracings suggest to her that time reckoning and astronomy were among the major motives of the people of Nazca. She claims there are too many conjunctions with astronomical directions to be coincidental.

Sir Eric Thompson's warning about playing with numbers in the study of the calendar also applies to the manipulation of alignment data. Thus, while one's analysis gives positive results, that of another investigator often indicates the reverse. Astronomer Gerald Hawkins (1975) disagrees with Reiche's conclusions. He undertook a survey of twenty-one triangles and seventy-two linear features to draw his negative results. Although his study was much briefer in scope, after computer matching 186 directions with lunar and solar extrema, equinoxes, and stellar positions, he concluded that any connection between the alignments and astronomy is the result of statistical coincidence. However, his "shotgun" technique of matching every measured direction with all conceivable astronomical points was already criticized when he applied it to Stonehenge. Reiche and Kosok had supposed all along that if astronomical alignments were related to the Nazca lines they were never more than a part of the total picture. One could not expect all of them to be astronomically aligned; therefore, statistics on the number of alignments pointing in astronomical directions might be of little use. Hawkins utilized the coordinates of forty-five bright stars in addition to all the key solar and lunar positions.¹⁶ Upon comparison of the number of astronomical matches obtained with that expected from the laws of probability for a random array of alignments, he found the astronomical hypotheses wanting; therefore, he rejected it totally.

Though the Nazca lines have enjoyed immense popularization in the literature, the last word on their astronomical significance is yet to be written. This statement can be expanded to serve as a general conclusion about our knowledge of the practice of astronomy by the native people of the regions to the north and south of Mesoamerica. In this chapter we have attempted to review the case studies which constitute a beginning of our understanding of native mental systems. From Nazca through the Caracol to the medicine wheels, investigators are finally gathering the hard facts on the subject of astronomical orientations. The total speculation which dominated the literature up to the first half of this century has now finally begun to meet the acid test of observation.

A hidden similarity has emerged from our study of astronomy in the standing architecture among Native American civilizations. It is that the horizon seems to be the underlying basic reference circle and the zenith the fundamental pole in every system we have discussed. By contrast, civilizations developing at higher latitudes, for example, the Babylonians and the Chinese, employed a celestial pole-celestial equator (or ecliptic) reference system. Some scholars seem to view the horizon system as characteristic of primitive cultures, but geographic determinism rather than a lack of sophistication may have more to do with the preference of this scheme over the polar frame by practical-minded tropical cultures. As we have seen in Chapter III, near the earth's equator natural celestial motion is not circulatory about the ce-

lestial pole as pivot, but rather quite vertical. Stars rise and fall on paths nearly perpendicular to the horizon. The possibility for fixing a direction on the horizon and holding it there for a length of time has allowed the Polynesians to navigate over large distances by using a star-at-horizon concept. We wonder if the ancient Andean people had not sought the same means for land navigation over the mountains of Peru. Perhaps the *ceque* lines of Cuzco and the lineations on the Nazca desert might find a similar interpretation with further study.

Historian Lewis Hanke (1974), in his reportage on Friar Bartolomé de las Casas' defense of the American Indian intellect, a generation after the conquest, condemns a statement reflecting the majority view in 1550. It was written by John Major, a Scottish geographer, and it displays the absence of careful thought about Indian ways at that time: "There is yet something else. Those people live like beasts on either side of the equator and between the poles men live like wild beasts, as Ptolemy says in his *Quadripartite*, and now this has been discovered by experience . . ." The implication, derived from the Greek philosophers who applied it to the Moorish people of Africa, was that people who lived in the heat of the Tropic or in the severe Arctic cold could hardly be capable of reasoning. Four centuries later do we yet have difficulties appreciating any environment for rearing the human intellect other than our own?

**Appendix A. Selected Building Orientations in Mesoamerica
Determined with Surveyor's Transit and Astronomical Fix**

(Sites containing buildings in the 17° family are underlined)

Site	Structure	Orientation	Approximate Building Period
Acancéh, Mex.	Pyramid, façade	188°45'	Classic
Aké, Mex.	Various walls	8°11' 9°59' 10°08'	Late Classic
Altun Ha, Bel.	Str. A-1 façade	100°50'	Late Classic?
Atzompa, Mex.	Ballcourt	4°15'	Early Classic?
	Las Grecas Patio	86°50'	
Balché, Mex.		308°50'	
Becan, Mex. **	Various walls	9½° 11½°	Classic
Caballito Blanco, Mex.	Str. P	294°09'	Pre-Classic
	Str. N	293°00'	
	Str. O, base	65°57'	
	Str. O, "arrow point"	{ 249°43', 251°18'	
Calixtlahuaca, Mex.	Temple of Tláloc, front	91°50'	Post-Classic
	Temple Quetzalcóatl, front	91°12'	
<u>Cempoala</u>	Str. D (round structure)	98°21'	Post-Classic
(<u>Zempoala</u>), Mex.	Templo de Los Aires (round structure)	109°32'	
Chacmultún, Mex.	Xethpool Grp.	289°54'	

Appendix A
—(continued)

Site	Structure	Orientation	Approximate Building Period
<u>Chalcatzingo, Mex.</u>	Flight of Steps, lower level	17°17'	Pre-Classic
	Flight of Steps, upper level	21°22'	
Chicanná, Mex. * *	Various walls	1½°	Classic
		11½°	
		359°	
<u>Chichén Itzá, Mex.</u>	Nunnery, façade	11°18'	Classic
	Casa Colorada, façade	282°18'	Classic
	Great Ballcourt, axis	17°24'	Post-Classic
	Tzompantli	17°36'	Post-Classic
	Platform of Venus	17°18'	Post-Classic
	Osario, façade	288°18'	Post-Classic
	Castillo	21°12'	Late Classic
	Temple of the Warriors	290°06'	Late Classic
	Caracol (upper platform)	22°54'	Late Classic
	Temple of Jaguars	16°06'	Post-Classic
	Retablos	290°18'	Classic
	Mercado	279°35'	Classic
	Sacbe	05°24'	Classic
	Casa Redonda	284°59'	Classic?
	Buildings at Chichén Viejo, axes	178°28'	Classic
		178°31'	
Cholula, Mex.	Various faces	26°16'	Classic
		24°15'	
		23°47'	
		25°32'	
		25°38'	
Chunyaxché, Mex.	Pyramid, façade	339°02'	Classic
Coatetelco, Mex.	Ballcourt, axis	160°17'	Late Classic
Cobá, Mex.	Bldg. 7, 2 façades	279°21'	Classic
		187°43'	
Comalcalco, Mex. *	Various walls	22°	?
		24°	
		26°	
Copán, Hond.	Great Plaza, east side	354°09'	Classic
	Great Plaza, west side	353°13'	
	Ballcourt, axis	353°29'	
	Hieroglyphic Stairway, top	0°52'	
	Hieroglyphic Stairway, base	1°15'	
	Temple 11, façade, base	1°17'	
	Eastern Court, west side	8°42'	
	Temple 22, façade	7°40'	
	Western Court, base, north side	5°27'	
		9°36'	
	Temple 32, façade	5°32'	
	Temple 16, façade	5°58'	
<u>Cozumel Island, Mex.</u>	Punta Islote	193°14'	Post-Classic
	El Cedral	289°05'	
	Str. 13	106°01'	
	Str. 14	118°02'	
	Str. 15	116°27'	
	El Real	106°27'	
Cuiculco, Mex.	Ramp of round temple	97°38'	Pre-Classic
		95°42'	
		91°43'	

Appendix A—(continued)

<i>Site</i>	<i>Structure</i>	<i>Orientation</i>	<i>Approximate Building Period</i>
<u>Dainzú, Mex.</u>	Principal Temple, façade Ballcourt, axis	297°13' 196°22'	Early Classic
Dzibilchaltún, Mex.	Temple of the Seven Dolls	273°50'	Pre-Classic
Dzibilnocac, Mex.	El Palacio	10°56'	Classic
El Mecer, Mex.		183°29'	
El Tajín, Mex.	Str. A, Face Pyramid of Niches	205°22' 96°03'	Post-Classic
Etzna, Mex.	Five-story palace	6°41'	Late Classic
Hacienda Poxolá, Mex.	***	359°	Late Classic?
Hochob, Mex.	Str. I	287°43'	
Hopelchén, Mex. (Culecab)	***	205°20'	Classic
Huitzo, Mex.	Walls	87°32' 82°48'	Pre-Classic
Ikil, Mex.	***	23°08'	Classic
Itzimté, Mex.	***	16½°	
<u>Izamal, Mex.</u>	Kinich Kakma, lower façade	14°06'	Post-Classic
Kabáh, Mex.	Codz Pop, façade Palace, façade Great Pyramid, façade	283°36' 282°12' 278°45'	Classic
Kaminaljuyú, Gua	Str. A	7°16'	Pre-Classic
K. 114, Hwy. 307, Yuc.**	***	5°	Post-Classic?
Kohunlich, Mex.	Palace of Masks	00°46'	Classic
Labná, Mex.	Str. 14, façade	192°02'	Classic
<u>Lambityeco, Mxc.</u>	Principal temple, façade	295°06'	Early Classic
<u>Malinalco, Mex.</u>	Str. IV, façade Str. II, façade Str. III, façade Str. I, façade Teotihuacán-style ballcourt, axis	105°09' 93°27' 102°16' 184°05' 297°05'	Post-Classic Pre-Classic
<u>Manzanilla, Mex.</u>	Aztec-style ballcourt, axis Castillo	117°02' 4°35'	Post-Classic Post-Classic
Mayapán, Mex.	Chac Temple, façade Round tower, façade Hall of Columns, façade	192°45' 192°47' 191°38'	 Post-Classic
Mitla, Mex.	Fortress Ballcourt, axis	193°07' 191°05'	 Post-Classic
Mixco Viejo, Guat.	Ballcourt No. 1, axis	05°31'	Early Classic
Monte Albán, Mex.	Ballcourt No. 2, axis Str. P, face Str. U, face Str. G, face Str. IV, face Str. I, face Str. S, face Str. Q, face Str. J, face Str. J, "arrow point" Danzantes, face Str. M, face	10°08' 272°34' 275°51' 04°48' 95°01' 183°18' 274°29' 273°49' 48°30' 221°10' 93°15' 96°17'	 Pre-Classic

Appendix A—(continued)

<i>Site</i>	<i>Structure</i>	<i>Orientation</i>	<i>Approximate Building Period</i>
Mul-Chic, Mex.	***	25°36'	Classic
Nohoch Mul, Mex.	Pyramid, façade	220°41'	Classic
Nohpat, Mex.	***	13°14'	Classic
		14°57'	
Olympic Village, Mexico City*	Various walls	0°	?
<u>Oxkintok, Mex.</u>	***	16°21'	Classic
Palenque, Mex.	Temple of the Inscriptions, façade, base	21°55'	Classic
	Temple of the Sun, façade, base	119°28'	
	Temple of the Cross, façade, base	211°45'	
	Temple of the Foliated Cross, façade, base	312°35'	
	Ballcourt, axis	13°29'	
Playa del Carmen, Mex.*	***	27½°	Post-Classic
Quiriguá, Guat.	Str. 1, façade	347°28'	Classic
	Str. 5, façade	351°08'	
	Str. XIII, façade	350°06'	
Río Bec, Mex.	Temple B	6°34'	Classic
San José Mogote, Mex.	Rosario phase group, east wall	3°24'	Pre-Classic
San Martín, Mex.	Pyramid, face	283°15'	Pre-Classic
<u>Santa Cecilia, Mex.*</u>	Various walls	17°	Post-Classic
		18½°	
Santa Rosa Xtampak, Mex.	Palace	208°29'	
Sayil, Mex.	El Palacio	192°23'	Classic
	Mirador**	4°	Classic
Seibal, Guat.	A-3 façade	276°59'	Post-Classic
<u>Tancah, Mex.**</u>	Bldg. 12, façade	19°	Post-Classic
Teayo, Mex.	Castillo, face	268°04'	Post-Classic
Tenayuca, Mex.	Pyramid, west façade	287°42'	Post-Classic
<u>Tenochtitlán, Mex.</u>	Temple of Huitzilopochtli, base, southwest corner	97°06'	Post-Classic
Teopanzolco, Mex.	Principal structure, face	270°43'	Post-Classic
Teotenango, Mex.	Acropolis, base	283°33'	Post-Classic
<u>Teotihuacán, Mex.</u>	Street of the Dead	15°28'	Pre-Classic
	East-west avenue	106°30'	
	Ciudadela	106°55'	
<u>Tcopozteco, Mex.</u>	Temple, face	287°42'	Post-Classic
Tikal, Guat.	Q complex, axis	5°28'	Classic
	P complex, axis	2°10'	
	Str. I, façade	280°35'	
	Str. II, façade	99°07'	
Tlatelolco, Mex.	Principal structure	281°47'	Post-Classic
	Nine building epochs	279°57'	
		279°43'	
		279°36'	
		278°58'	

Appendix A—(continued)

Site	Structure	Orientation	Approximate Building Period
		279°30'	
		279°09'	
		279°30'	
		277°39'	
Tompul, Mex.**	***	11°	Post-Classic
<u>Tula, Mex.</u>	Temple B, face	197°04'	Late Classic
	North Ballcourt, axis	106°25'	
		107°06'	
	North Ballcourt, south (short wall)	14°55'	
		14°13'	
	South Ballcourt, axis	15°04'	
	Tula Chica (round, structure), face	98°42'	Post-Classic
Tulum, Mex.	Castillo, façade	111°37'	Post-Classic
Uaxactún, Guat.	E-VII-Sub, façade	87°43'	Early Classic
	A-XVIII, façade	85°51'	
Uxmal, Mex.	House of the Magician, façade	99°	Classic
	Governor's Palace, façade	118°05'	
Xcanacruz, Mex.		115°00'	
Xcaret, Mex.	Grp. D, round structure	223°59'	Post-Classic
<u>Xelha, Mex.**</u>	***	18°	Post-Classic?
Xkichmook, Mex.	Principal structure	18°41'	
<u>Xlapak, Mex.**</u>	***	15°	Classic
<u>Xochicalco, Mex.</u>	Str. E, face	180°25'	Late Classic
	Ballcourt 1, axis	90°44'	
	Str. A (Temple of the Plumed Serpent), face	276°45'	
		277°13'	
	Ballcourt 2, axis	300°35'	
Xpuhil, Mex.	Str. 1	7°45'	Late Classic
Xunantunich, Bel.	Stucco Palace	261°40'	Late Classic
Yagul, Mex.	Patio	207°06'	Post-Classic
	Ballcourt	201°21'	
Yaxché Lahbpak, Mex.		15°52'	
Yaxcopoil, Mex.**	***	4°	Classic
Yueuita, Mex.	Platform D, face	205°42'	Early Classic?
	Str. A, face	48°05'	
Yucuñudahui, Mex.	Ballcourt	250°03'	Monte Albán III
Zaachila, Mex.	Plaza	288°30'	Post-Classic

* After Dursin (1968), corrected magnetic compass measurements.

** Author's observations, corrected magnetic compass.

*** Largest, usually only, standing structure.

The arguments relating to each of the Native American astro-archaeological case studies reported in this chapter have been necessarily brief. For an expanded version of each inquiry, the reader is invited to examine the following published original sources and references therein, which I have drawn upon in composing this portion of the text.

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Postscript

"The real question is not whether the touch of a woodpecker's beak does in fact cure toothache. It is rather whether there is a point of view from which a woodpecker's beak and a man's tooth can be seen as 'going together' (the use of this congruity for therapeutic purposes being only one of its possible uses), and whether some initial order can be introduced into the universe by means of these groupings."

—Claude Lévi-Strauss (1969, p. 9)

In this book I have attempted to synthesize the significant recent data from the world of Native American archaeoastronomy and to introduce it as unencumbered by disciplinary jargon and as free of complex prerequisites as I could imagine it. Where the task became difficult I have delineated the skills necessary to sensibly deal with the arguments.

Archaeoastronomy is a field that has grown to encompass all cultures and all forms of evidence relating to the astronomy of developing civilizations. Its explosive evolution in the 1970s has served to focus our attention upon more than just a "piece of the present."

I hope that the synthesis offered in this volume will prove useful to those involved in both Mesoamerican and non-Mesoamerican studies. As scholars from established fields begin to work with some of the problems raised by the archaeoastronomers, they will find that the burden of proof also rests upon their shoulders. We have questions for culture historians, archaeologists, current ethnologists, astronomers, cultural anthropologists, epigraphers, and historians of science. We have also offered them evidence; consequently, they must find a place in their milieu for the archaeoastronomical disclosures which they find acceptable on the basis of considered and objective judgment.

Perhaps it is our own cultural upbringing that causes us to retreat to the same question: Were the most advanced ancient Mesoamerican astronomers practicing true science? Almost irrationally, our appreciation of the value of their intellect ultimately seems to hinge on this query. The question becomes less meaningful when we understand that the Native American style of perceiving nature was different from our own. And their pursuit of knowledge was also different but nevertheless worthy of our consideration, as Lévi-Strauss reminds us in the heading to this postscript. Theirs was a totally different belief sys-

tem. Many of the things we think about never concerned them, and their concepts seem quite foreign to the Western modernist. A principle of cosmic harmony pervaded all of existence in Mesoamerican thought. In a view we would regard as passive, the human individual was as much a part of the total system as was the planet Venus or a grain of sand. There were no proportionalities. The course of one component of the cosmos was bound to all others. This is quite a different view from that of the modern scientists who try to dismantle via cause-effect relationships one specific action or event in the natural world from another, only ultimately to recombine them to form a unity of their own. The scientists' notion of explanation through prediction, their scientific curiosity, and their will to harness the forces of nature possess no analogs in Native American systems of thought. Our study of their way teaches us that the Maya no more cared about what the moon was made of than we care about the planting of our crops to coincide with the heliacal rising of the Pleiades.

Nevertheless, those who feel compelled to give an answer to the scientific question should perceive that the Maya could have developed their astronomical warning tables in the codices only through naked-eye observational techniques, oft encoded in the architecture and passing through successive stages of refinement over long periods of time. We must view their calendar as a predictive device, the accuracy of which improves with time as better observations are made. In this sense one may accommodate Aaboe's definition of scientific astronomy (see p. 220).

But to force-fit Native American astronomy into the Western mold only diminishes our understanding of it. For the uninitiated, the Mesoamerican "cosmovision" is too easily colored by our dim view of the ancients' motives and often diminished by our own Western habit of visualizing the universe as a hierarchy of orbits in a well-defined space rather than time cycles in an eternity. The elevated nature of the Mesoamerican temporal view of the universe is perhaps best seen in our review of the lunar tables in the Dresden Codex. While the Maya had no geometric concept of the nodes of the lunar orbit, the scant records available tell us that they were able to abstract a totally separate system for dealing quite successfully with eclipse prediction, though the details still escape us. As far as the lunar node was concerned, they had no need for it in their hypothesis. Nor were they dependent on sightings of the swing positions of the moon at horizon as were the Megalithic people of ancient Europe. Ultimately, the Maya became as free as the Babylonians and the Greeks from the task of making daily observations in order to know with surety where and when celestial events would occur. Their skywatching was practiced in order to strengthen the universal models which we see so concisely encoded in their inscriptions.

Some will think our words of warning about the need to suppress our "Western presentist" attitude when studying ancient astronomy have been stated too frequently and too forcefully. Indeed there are numerous instances, all too obvious in this text, where I, unable to retreat from my own Western astronomical training, have been compelled to couch my explanations in the familiar mode ordained by tradition. It is

my opinion that the distance between their and our mental view of the natural world can never be underestimated. This distance looms as the highest barrier we must penetrate if we can ever hope to reach into the ancient mind. When we begin to commit ourselves to observing and analyzing instead of judging and evaluating non-Western ancient astronomical systems, we shall have overthrown an existing paradigm which obstructs the pathway of knowledge in the field of archaeoastronomy. It is hoped that our study of the astronomical system of a foreign extinct culture which flourished in isolation can better help us to understand the nature of human rather than purely Western intellectual achievements.

Our discussion of Mesoamerican astronomical systems has focused largely upon the world of the Maya. Here lies a written record which, though scant in volume, is rich in detail. An abundant iconography supplements the material record which survives that culture. My examination of their astronomy leaves me with a feeling of admiration and sadness for those who developed it, coupled with remoteness and ignorance, for we know precious little with certainty. Who can say how things would have progressed had the conquest never come? Perhaps the greatest frontier in archaeoastronomy lies in the exploration of the other cultures of the Americas, the Hopi and Navaho to the north and the civilizations of the Andes to the south. The South American chronicles and *quipus* have scarcely been touched by scholars inquiring on astronomical matters there, but already we have seen enough to realize that our knowledge of their mental system has been entombed too long because of our refusal to confront a culture devoid of the written word as we know it.

Finally, one cannot read a text on the subject of archaeoastronomy without embracing controversial questions related to cultural diffusion, world myth, and Jungian archetypes. Those who have encountered Brahmanic cosmology are all too familiar with color-coded cardinal directions, buildings with cardinal orientations, directional deities, and sky bearers. Old World astronomy possessed a zodiac along with many other astronomical concepts which have reared up in this work. Would we naturally expect such similarities because we all behold but a single unchanging universe filtered through the standard human eye? Or is the Maya use of time so uniquely different from that which we find among other developing civilizations? Such questions are still beyond the scope of our collective competence. If I have been able to provide fuel for the fires of debate on such basic inquiries, then the principal goal in assembling this deposition will have been attained.

Notes

II. The Historical and Ethnographic Background for Native American Astronomy

1. This cycle was among the most important in Mesoamerica. We defer a discussion of its detail to Chapter IV.
2. The origin of this important calendric cycle and its connection with the zenith sun will be discussed in Chapter IV.

III. Astronomy with the Naked Eye

1. These "true" cardinal points should not be confused with the cardinal points of the compass, which are defined relative to the earth's magnetic poles. Distinct from the north geographic pole, the north magnetic pole is situated in northern Canada in geographic latitude 75° N, and the magnetic compass usually points in that general direction, barring any local anomalies (which turn out to be quite common). The deviation of the magnetic compass from astronomical north is termed the *magnetic declination*, or *variation*. Today in Mesoamerica, the magnetic declination lies generally east of true north by 3° to 8° . However, the amount varies irregularly by a few degrees per century. The magnitude of the change can be quite large at locations closer to the magnetic poles—it varied by 20° over the last century at London. Seasonal fluctuations including daily variations of up to $1/2^{\circ}$ (all of unknown origin) are not uncommon. The change of magnetic deviation through time in Mesoamerica is discussed in Appendix E, this chapter. These developments render even the most sophisticated magnetic compass a useless device if accurate directional information is required. See D. Wolfman (1973) for a full discussion of the problem.
2. In Fig. 17 our observer (O) is placed on a horizon plane HH' on the surface of the earth at an angular distance of L degrees north of the earth's equator as viewed from the center of the earth, C. This defines his latitude. Again Z is his zenith and P the north celestial pole. The altitude of the celestial pole is measured by the angle S between OH' and OP. Since the celestial sphere may be arbitrarily large, the direction in space to the celestial pole as viewed from anywhere on earth is the same. Thus, the line from the center of the earth to the north geographic pole (CG) extended is parallel to OP extended. Now, the straight line ZOC cuts this pair of parallel lines; therefore, the angles ZOP and OCG are equal. But ZOP is $90^{\circ} - S$ and OCG is $90^{\circ} - L$; thus, S must equal L and the proof is complete.
3. One of two intersections of the ecliptic and the celestial equator, the *vernal equinox* represents the point at which the sun, in its annual motion along the ecliptic, crosses the celestial equator from the southern to the

northern hemisphere of the celestial sphere; this event occurs about March 21. The *autumnal equinox* is the point 180° opposite V on the celestial equator (not shown), where the sun is stationed about September 21. Unfortunately, no bright star marks either of these important reference points. As we shall see in Appendix B, the vernal equinox actually shifts relative to the stars over long periods of time. However, this fact is of no relevance at this stage of the discussion.

4. From simple trigonometry, one can show that the rising azimuth, A , of any celestial body is given approximately by

$$\cos A = \frac{\sin \delta}{\cos L}$$

where δ is the declination of the body and L is the observer's latitude. The setting azimuth is $360^\circ - A$.

5. At the present time the approximate lengths of the seasons are autumn 91 days, winter 89 days, spring 92 days, summer 93 days. Winter is the shortest season, but the perihelion passage date (time of closest approach of earth to sun) also changes with time. Ten centuries ago it occurred about December 16, twenty centuries ago about December 1. Thus, at that time autumn was the shortest season.
6. Astronomers refer to an "occultation" as the passage of the moon or any of the planets in front of a star or of the moon in front of any of the planets. The term "eclipse" is reserved solely for sun-moon interactions.
7. This is only approximately true. As we shall see, the *plane of the moon's orbit also shifts*, so the moon can never trace a closed circuit with respect to the stars. Its apparent orbit on the sky is open ended. By the time the moon returns to the region of the same star it occulted one sidereal month ago, it actually passes slightly to the west of that star. In any event, it would take some very skillful observing and averaging over a long time base to accurately deduce the sidereal period.
8. Letting ϵ = the obliquity of the ecliptic and ι = the lunar inclination, a major standstill is said to occur at $\pm (\epsilon - \iota)$ and a minor standstill at $\pm (\epsilon + \iota)$. The standstills and the nine-minute wobble are treated in great depth by Thom (1971), who contends that they were observed in prehistoric Britain.
9. The darkness at mid-day produced by a solar eclipse is known to invoke fear among many tribes which still lead an aboriginal existence. During the total eclipse of 1973 across Central Africa, one anthropologist noted that the natives banged pans together and worriedly chanted for the return of the sun god.
10. Uranus lies at the threshold of naked-eye visibility. Conceivably, it could have been discovered by very careful observers.
11. While the sun-centered scheme may introduce a classical Western bias into the discussion, about which we were already forewarned in Chapters I and II, we nevertheless employ this device because it greatly simplifies our understanding of planetary motions. Also, it serves the added advantage of helping us decide whether ancient astronomers needed to posit the concept of centrism when they dealt with planetary motion.
12. Actually, the Venus synodic period is 583.92 days and, owing to the noncircular nature of the orbits of Venus and Earth, it can vary between 579.6 and 588.1 days. Any five consecutive Venus cycles average out to 584 days.
13. To verify that Venus is a morning star in this position, let the observer's horizon be represented by a straightedge held tangent to the earth's surface in the figure. Rotate the straightedge over the circle representing the earth in a clockwise direction, the same sense in which the direction of revolution about the sun occurs, always being careful to keep it tangent to the earth's surface. The planet at position 2 will rise above the horizon ahead

- of the sun, thus appearing low in the east at sunrise. Conversely, it rises after the sun in position 8, when it is an evening star in the west.
14. For Mercury the corresponding angle is only 26° , thus making the planet much more difficult to view.
 15. We note in passing that the true interval of appearance of Venus as morning and evening star is close to 260 days, a very important number in the Maya calendar, as we shall see later.
 16. The rising of a star at the same time as the sun is termed its *cosmic rising*, while the rising of a star at the instant of sunset is defined as its *achronic rising*. Conversely, a star sets cosmically at the instant of sunset and sets achronically opposite the rising sun. Though mentioned occasionally in the astronomical literature, these events are of little importance to naked-eye astronomy, since, unlike heliacal phenomena, they do not constitute directly visible events.
 17. The following more exact formulations, though not as obvious, are easily derivable from spherical trigonometry:

$$\Delta A = \frac{\tan L}{\cos(A_0 - 90^\circ)} , \quad \text{always taken as positive for a rising object on an elevated horizon;}$$

$$\Delta A = \frac{\tan L}{\cos(A_0 - 270^\circ)} , \quad \text{always taken as negative for a setting object on an elevated horizon}$$

18. The declination values given in Table 11 are accurate to one day for any given year.
19. For ease in performing calculations, the watch is calibrated in Greenwich Mean Time (GMT, Eastern Standard Time plus 5 hours). On the sample data sheet we list the watch correction, determined from the radio signal to be 39 seconds slow at the time. The correct GMT, then, is recorded as 21:12:06.
20. The declination of the sun may be obtained by interpolation from Table 11. Where greater precision is required, one may consult the Ephemeris. The Equation of Time (Eq.T) is tabulated in Table 13. A more accurate Eq.T can be determined as the difference: "Ephemeris Transit" minus solar noon ($12^{\text{h}}00^{\text{m}}00^{\text{s}}$) in the last column of the table entitled "Sun for Zero Hours Ephemeris Time" on the early pages of the *American Ephemeris and Nautical Almanac* for the year of the observations. The latter correction alters the averaged position of the sun, by which we keep our watch time, to its apparent position in the sky. Were it not for the nonuniformities of solar motion coupled with our desire to keep uniform time, this correction would not exist.

IV. The Mathematical and Astronomical Content of the Mesoamerican Inscriptions

1. Later, Sir Eric Thompson's *Catalog of Maya Hieroglyphs* (1962), along with Gunter Zimmerman's *Die Hieroglyphen der Maya Handschriften* (1956), gave researchers the most complete listing and description of Maya written forms in three decades.
2. Such a notation would seem to emphasize the importance of the western horizon, for only a viewer facing west would refer to the north as being on the right-hand side of the sun and the south on the left. Also, perhaps the Mesoamericans, more concerned about the completion of cycles, observed the disappearance of objects in the west.
3. Epigraphers generally refer to glyphic blocks by vertical column, labeled A, B, C, . . . , from left to right and by horizontal row, labeled 1, 2, 3, . . . , from top to bottom.

4. Higher orders than the baktun were known though employed only infrequently; therefore, extreme lengths of time must have had some significance for the Maya. For example, on the stone of Chiapa we find recorded the number 13.13.13.1.1.0.11.14 (10,245,607,434 days, or nearly thirty million years!) (Morley, 1938, 1:313-315).
5. If at first glance the idea of using a different count for time seems unusual, consider our own method of timekeeping. The second and minute units on our clocks turn over after 59 instead of 99. There is, incidentally, no universal agreement on the difference between the two counts; for example, Kelley (private communication) believes the trade count may never have existed at all.
6. Thus, the last days of a baktun and those beginning a new cycle would be counted

12.19.19.17.18

12.19.19.17.19

13.0.0.0.0 (written 0.0.0.0.0)

13.0.0.0.1 (written 0.0.0.0.1)

etc.

Actually, we know of no dates written between 13.0.0.0.0 and 1.0.0.0.0, so we cannot be sure whether they are written with baktun coefficient 13 or 0. Furthermore, it may be misleading to state that the count returned to zero after 13 baktuns in all representations. For example, Thompson (1950, p. 314) illustrates one case where the addition of 9.8.9.13.0 and 10.11.10.5.8 gave 1.0.0.0.0.8!

7. Four "cycle 7" Long Count dates have been recorded, and only a few more inscriptions opening with baktun 8 have been discovered.
8. The zoomorphic nature of many of these abstract glyphic symbols is visible upon close inspection: for example, Oc is a coyote; Chuen, a monkey; Ix, a spotted jaguar; and Imix, a beetle.
9. The count may instead have proceeded from 1 to 20, the twentieth day representing the seating of the next month. We adopt the 0-19 notation.
10. See also the discussion in "The Mesoamerican Philosophy of Numbers" and note 2, this chapter.
11. A pocket electronic calculator is ideal both for this sort of computation and for future calculations to be made in this chapter. Many such devices are easily programmable to perform Maya arithmetical calculations.
12. To avoid confusion in making calculations, we write the zero point of the Long Count as 0.0.0.0.0 instead of 13.0.0.0.0.
13. The outer "dots" on glyph blocks 4 and 5 are purely decorative.
14. Whether the lord ruled the night preceding or following the Long Count date is not clear, but the answer would depend on what hour commenced the Maya day. We have no evidence bearing on this question.
15. Satterthwaite (1947, pp. 86-106) has given a complete discussion of lunar factors, regarding some more seriously than others (the 81 count a little less seriously). In the present discussion, I make no attempt to evaluate the myriad lunar factors that researchers have proposed. I only intend to show that by using some lunar grouping technique one can both determine the length of the synodic month and predict eclipses. But see Appendix A, Table 23, for a means of using lunar information on the stelae as a test of correlations.
16. The pictures seem to be associated with death, evil omen, or malevolence of some sort. Each one hangs from a celestial band surmounted by literary glyphs, many of which possess an ominous nature.
17. As Kelley and Kerr (1974, p. 183) have pointed out, the number 11,960 represents a convenient choice if the astronomers desired to relate eclipses to

other astronomical cycles. For example, it is also 32 tropical years with a remainder of .745, or nearly three-fourths of the year. Thus, the interval could have been used for tropical year calculations, say to jump from solstice to equinox. After four repetitions, the ephemeris would return to nearly the same place in the tropical year.

18. It is also a very good eclipse cycle, as a glance at Table 5 suggests. The numbers 1,033, 1,565, and 2,598, all of which appear in the Dresden Table, are also cited in Table 5.
19. For two recent reviews of the Maya interest in Venus, see Aveni (1979b) and Closs (1979).
20. We have tried to label the categories of information content in Figs. 62 and 63 similarly. Thus, I refers to Long Count dates and VI to pictures.
21. Quetzalcóatl, the Aztec counterpart of Kukulcan, has been identified with Tlahuizcalpantecuhtli, the "Lord of the House of the Dawn," who is Venus the morning star. Venus gods are also associated with similar tables from the Borgia group of codices from Central Mexico (Seler, 1904c).
22. Conversely, Motolinía (1903) tells us that the Central Mexicans allotted 260 days (close to the actual interval tabulated in Table 6) for the evening and morning star appearances. In some quarters 273 days were counted (Seler, 1904c, p. 359). One wonders if Motolinía might be confusing the former interval with the famous ritual cycle or could the Venus period have contributed to the origin of the ritual cycle?

Two other points about these numbers are worth mentioning: (1) if we link the intervals $a + b$, we find $236 + 90 = 326$, which can be regarded as a close approximation to 12 lunar *sidereal* months, and (2) the sum of 177 and 148 (6 + 5 lunar synodic months), two familiar numbers from the lunar table in the Dresden Codex, gives nearly the same period. These little coincidences further reveal the Maya priests' desire to unify the calendar by attempting to integrate as many celestial cycles as they could into their astronomical almanacs.

23. It is curious that the Babylonians also counted a three-month disappearance interval, indicating that the planet would move approximately one-fourth of the way around its cycle in the tropical year (Pannekoek, 1969, p. 33).
24. Originally preceding pages 46–50, this page, found detached, was misnumbered by modern scholars.
25. It should be 9 Ahau. The scribe made an error.
26. Block II-5 is almost totally effaced. M. Closs (1977) has proposed the reading

Col. G	5.5.8.0	(1 Ahau) + 37,960 days + 65 Venus revolutions
Col. F	10.10.16.0	(1 Ahau) + 75,920 days + 130 Venus revolutions
Col. E	15.16.16.0	(1 Ahau) + 113,880 days + 195 Venus revolutions
Col. D	1.1.1.14.0	(1 Ahau) + 151,840 days + 260 Venus revolutions

27. The discerning eye will note that 1.5.5.0 (not 1.6.0.0) is the number which actually appears in the table on lines 6–8, column G. It has been altered by Thompson—who assumed the scribe committed an error—in order to force fit actual observations of Venus to predictions made using the table. M. Closs' (1977) analysis proposes a correction scheme which uses the original 1.5.5.0 along with the other three numbers once each. While Thompson (1972b) (and Teeple [1930] before him) analyzed page 24 as a mechanism for shifting the base of the Venus table, Closs views the correction page as a date-reaching device, a concept which he suggests is more consistent with the idea that the tables were intended as a field manual for the lay priest to determine the appropriate time to perform certain auguries relating to the appearance or disappearance of the planet at horizon.

28. To add to the integrative nature of Maya calendars in the codices, Spinden (1930, p. 92) has pointed out that the formal *lunar* calendar of 11,960 days connects significant points in the Venus calendar; for example, 1 Ahau 18 Kayab (one of the Calendar Round dates written in the Venus table) plus 11,960 days equals 1 Ahau 13 Mac, another written Calendar Round date. Spinden shows that the same 11,960 (we will remember it as the length of the lunar eclipse table on Dresden 51–58) can be tied to the starting date of the table, 9.9.9.16.0. See also Smiley (1973).
29. Smiley (1975) finds dates in the Venus table that are separated by 11,960 days, the intended length of the lunar table. Accordingly, he proposes that the Maya may have been attempting to correlate eclipse cycles with the heliacal rising of Venus. One such date serves as the basis of his conclusion (see Appendix A).
30. Among the eight Long Count dates tabulated on this stela, Kelley and Kerr (1974) find intervals nearly equaling five multiples of the Jupiter synodic period (1, 4, 8, 32, and 40×398.88 days) and three multiples of the Saturn synodic interval (4, 4, and 8×378.09 days).
31. The number 364 is a conveniently factorable approximation to the length of the tropical year. As we shall see, it also appears on pages 23–24 of the Paris Codex where it could have been used to tally a “year” of 13 lunar sidereal months each of 28 days. It usually occurs in a series of 1,820 days, which is the equivalent of 7×260 or 5×364 or 65×28 .
32. According to Kelley (private communication), the number 9.19.8.15.0 should be regarded not as a Long Count but rather as an interval counted from a Ring Number and reaching the Long Count 9.19.7.15.8. The same holds for our earlier Venus number 9.9.16.0.0, which may be regarded as the interval from the Ring Number base to the Long Count 9.9.9.16.0.
33. We can see this easily from the basic planetary intervals given in Table 6, together with Fig. 35. Mars disappears behind the sun for 120 days, 60 days either side of conjunction. It is in retrograde motion for 75 days, about 38 days on either side of opposition. In the meantime, it spends roughly one-half of 660 days moving from first visibility to opposition; therefore, the interval between conjunction and the inception of retrograde motion is $60 + 330 - 38$, or 352 days.
34. Using Table 6: The interval from first appearance to retrograde is one-half of 660 days minus one-half of 75 days, or, roughly, 292 days. Adding one-half of 120 days, the disappearance interval, we arrive at an interval between conjunction and retrograde of 352 days. It should also be noted that 292 days is one-half the Venus cycle, a fact which may have been important for the Maya astronomer, who seemed to exhibit a propensity for the integration of celestial cycles.
35. According to the Motul and other contemporary dictionaries, certain stars in our modern zodiacal constellation of Gemini were called the “tortoise stars” (Landa, 1941, p. 133).
36. Severin (n.d.) in a recent Ph.D. thesis has elaborated a scheme for reading these Paris pages as a zodiacal sequence.
37. Kelley (private communication) suggests the double-8 or $8.8 = 178$ might refer to the six lunar phase count used to predict eclipses.
38. Recently, E. W. Andrews IV (1965) has noted an inconsistency between northern and southern Maya radiocarbon dates. The former seem to favor the Spinden correlation, while the latter fall into better agreement with the GMT correlation. “Andrews’ dilemma” is that neither correlation fits the archaeological data from both north and south. Kubler (1976) has concluded that, before the Initial Series method of counting was terminated (about 10.4.0.0.0), at least two base dates were in use at different cities. It

has also been suggested that separate chronologies, each having a different starting time, were employed to describe the history of various dynasties at a given city. The question must be regarded as quite open at the present time.

39. However, Spinden (1930, pp. 17–19) interprets this reading quite differently, suggesting that the katun count was misread and miscorrelated with the years by someone (writing in 1685) who had no understanding of the dates. Thus, both historical and astronomical arguments are open to attack.
40. Originally, Thompson gave 584,285 days, Goodman 584,280, and Martínez 584,281. What we are calling the Goodman-Martínez-Thompson (GMT) correlation is a modified version of the three, or 584,283 days (see Kelley, 1976, pp. 31–33).
41. To convert dates occurring after (the date of the Gregorian calendar reform), one must subtract 10 days. Thus, we would treat January 1, 1979, as if it were December 22, 1978.

V. Astroarchaeology and the Place of Astronomy in Ancient American Architecture

1. Wordsworth's "On Seeing the Foundation Preparing for the Erection of Rydal Chapel, Westmoreland" was written in 1823. He later remarked in an explanation, "Our churches, invariably perhaps, stand east and west, but why is by few persons exactly known, nor that the degree of deviation from due east often noticeable in the ancient ones was determined, in each particular case, by the point in the horizon at which the sun rose upon the day of the saint to whom the church was dedicated" (Dinsmoor, 1939, p. 102).
2. The cosmic order may also be expressed in one's house. Cunningham (1973) points out that the Atoni of Timor deliberately disorient their houses from east-west because, according to his informer, "that is the way of the sun" and "the sun must not enter the house."
3. But a glance back at Chapter III, where we discussed the zenith sun and the vertical motion exhibited by stars in tropical skies, suggests a very different perspective from that which confronted ancient astronomers at the higher latitudes.
4. The serious reader may employ Table 9 to approximate this result. Sirius, the brightest star in the sky, should be considered as a second possibility. It rose along the west-east axis of the city, undergoing heliacal rising at the summer solstice and last visible rising following sunset just before the winter solstice (see Table 10). Both possibilities had been suggested in 1967 by archaeologist James Dow.
5. The most uncertain variable in the calculation is precession of the equinoxes (Chapter III, Appendix B). The date of the establishment of the Teotihuacán grid pattern cannot be stated with an accuracy of less than a few hundred years, during which time the Pleiades (relatively rapid precessors) had shifted in declination by about a degree.
6. A line passing from the Cerro Gordo marker through Teotihuacán parallel to the Street of the Dead also cuts through the center of the Ciudadela as well as the Pyramid of the Sun.
7. We have already encountered the symbolism of the cross in an astronomical context in the form of the crossed-sticks in Chapter II. By the time of this writing the number of pecked crosses in the Teotihuacán environment had increased to sixteen. They include a marker located within $1/2^\circ$ of true west of the Pyramid of the Sun, which may have served as an equinox sun-

set marker and a pecked cross on Cerro Teponaxtle located close to the direction astronomical south relative to the Pyramid of the Sun. In each case, auxiliary markers on intervening hills blocking the view from the Pyramid also mark the alignment. There is now reason to believe that Teotihuacán architects erected a set of axes toward the "astronomical cardinal directions" as well as the "Teotihuacán cardinal directions." However, we do not yet understand the motivation for this dualism. Finally, the axes of three pecked petroglyphs on Cerro Chiconautla, located 10 kilometers southwest of the Pyramid of the Sun, were found to point to the Pyramid of the Sun and to within 3° of the summer solstice sunrise point at the same time. These recent facts make it clear that the relationship between the astronomy and architecture of the great ceremonial center of Central Mexico is far more complex than we had envisioned.

8. From the point of view of naked-eye positional astronomy, it should not be alarming to find an error of 10 to 20 kilometers in the determination of the northernmost place on earth where the sun can attain the zenith. Two kilometers on the earth's surface are the equivalent of one arc minute ($1/30$ the angular diameter of the sun). Furthermore, since the sun is an extended object, it will not cast a sharp shadow. Finally, whether a shadow-casting technique or direct view of the solar image through a tube is employed to solve the problem, the vertical direction would need to be attained quite precisely to pin down the special location. When Don Juan Pío Pérez told us that his ancestors "erred only 48 hours in advance" (see discussion in Chapter II) in determining the zenith passage date, he indirectly suggested that an error of thirty minutes of arc would not have been unreasonable.
9. Also, Jupiter and Mars were within 2° of conjunction on this date. Kelley (private communication) reads the Initial Series of Stela 12 as 9.10.15.0.0, which is 2,920 days (5 Venus rounds) prior to the 1 Ahau 13 Mac date of the Dresden Venus table.
10. E. Calnek (private communication) suggests that it was located even farther to the west than depicted in the model.
11. A few modern Maya living in the area, when queried recently as to the function of the building, replied that the ancient Maya held their great wedding ceremonies there. Sir Eric's simile was evidently taken quite seriously by the locals.
12. The Caracol derives its name from this staircase (more appropriately a narrow passage) which coils upward a full turn, imitating the shell of a snail—*caracol* in Spanish.
13. It is curious that the western jamb is tilted from the vertical by exactly the amount necessary to permit an exact registration of the sunset on the equinoctial dates. If it were straightened, the jamb would miss recording the precise equinox sunsets by a few days. This leads us to wonder if the disorientation might not have been deliberate.
14. Mayapán even displays a Castillo (also mentioned in the quotation) with as many tiers and steps as the larger archetype at Chichén Itzá. The orientation of the building (4°35' E of N) deviates from the prevailing 13° east-of-north pattern exhibited by most of Mayapán's buildings.
15. The recent work of J. Earls (1976) has documented the ecological function of the existing astronomical calendar of Moray, a community near Cuzco.
16. He failed to include astronomical phenomena relevant to the tropics, e.g., the sunrise point on the day of passage across the zenith. In fact, Hawkins' method of selection of archaeological alignments may be as subjective as his astronomical predilections; for example, he considered only the bisector of the numerous long thin triangles as a possible direction indicator.

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